CONCENTRATING ORES BY FLOTATION

BEING A DESCRIPTION AND HISTORY OF A RECENT METALLURGICAL DEVELOPMENT, TOGETHER WITH A SUMMARY OF PATENTS AND LITIGATION,

BY

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To the Teachers of Science in Leland Stanford Jr. University
who gave me the desire to know and to learn.

CONTENTS.

CHAPTER I.

Historical Sketch—Position of the Processes in the Art of Metallurgy—Inventory—Development—Haynes—Bradford—Everson—Robson & Crowder—Elmore (Old Process)—Van Meter—Potter-Delprat—Froment—Minerals Separation—Goyder & Laughton—Wolfe—Elmore (New Vacuum Process)—De Bavay—Gillies—Macquisten—Murex—Zinc Corporation—Hyde.

CHAPTER II.

Patents—Expired Patents—Unexpired Patents.

CHAPTER III.

Litigation—Decided Cases—Elmore v. Van Meter—Sulman & Picard v. Wolf—De Bavay v. Macquisten—Potter v. The Broken Hill Proprietary Co., Ltd.—Ore Concentration Co., Ltd., v. Webster and Others—Elmore v. Minerals Separation, Ltd.—Minerals Separation, Ltd., v. Norris—Minerals Separation, Ltd., v. Potter—British Ore Concentration Syndicate, Ltd., and Alexander Stanley Elmore v. The Minerals Separation, Ltd. Undecided Cases: Elmore v. The Sulphide Corporation, Ltd.—Potter v. The Sulphide Corporation, Ltd.—Minerals Separation, Ltd., v. De Bavay—Minerals Separation, Ltd., v. Hyde.

CHAPTER IV.

Theories—Surface Tension—Adhesion—Bubbles—Commercial Effectiveness—Soluble Frothing Agents—Coagulation.

CHAPTER V.

Tests—Experiments—Apparatus—Curves—Potter—Delprat—De Bavay—Macquisten—Elmore—Gasification—Deleterious Substances—Problems for Research.

CHAPTER VI.

The Potter-Delprat Process—Apparatus—Application—Working Costs—Recovery.

CHAPTER VII.

The De Bavay Process—Apparatus—Recovery—Application.

CHAPTER VIII.

The Elmore Vacuum Flotation Process—Apparatus—Working Costs—Application.

CHAPTER IX.

The Minerals Separation Process—Apparatus—Application—Recovery.

CHAPTER X.

Other Flotation Processes—Macquisten—Murex—Sanders—Horwood—Hyde.

CHAPTER XI.

Economics—Limitations—Separation of Sulphides—Combinations—Slime—Magnitude of Operations—Advantages—Broken Hill—Royalties—Costs—Conclusions.

CHAPTER XII.

Bibliography.

PREFACE.

This book is intended as an interim report of progress in a rapidly developing art. It is put forward in the hope that it may prevent duplication of labour on the part of ambitious inventors, and that it may give engineers not already familiar with the subject a starting point in the application of a new method of turning ores to account.

My debt to the labour and assistance of others can hardly be acknowledged adequately. To the directors of Minerals Separation, Ltd., cordial thanks are due for permission to publish much information collected during four years while acting as their general manager and consulting engineer. Although this permission is kindly granted, they are not necessarily in agreement with all the opinions expressed, and, in fact, quite properly oppose some of the views set forth.

To H. Livingstone Sulman and Hugh F. K. Picard, of the firm of Sulman & Picard, I am indebted for many ideas absorbed from them through three years of pleasant professional association (during which time they were consulting metallurgists to the above company). They have in preparation a book on the 'Theories of Concentration Processes Involving Surface Tension,' which will be a work of high scientific merit. I have endeavoured, I hope successfully, not to trespass on any new and unpublished ground, the announcement of which rightfully belongs to them; further, it is not my desire to present the subject in so profound a manner as they will do, deeming it of considerably more use to engineers to leave the discussion of the mathematical and physical laws involved for another occasion.

To the members of my former staff and others, Deane P. Mitchell, James M. Hyde, James Hebbard, E. J. Horwood, Henry Lavers, Edward H. Nutter, George W. Thompson, H. H. Greenway, A. Howard Higgins, George A. Chapman, A. Sydney Stevens, E. Ray Wilkinson, Alfred K. Burn, A. C. Howard, George C. Klug, C. J. Hylton, John Leechman, F. Glynn Price, and E. E. Wood, I am indebted to an extent that the mere mention of their names but scantily requites.

The files of the current technical journals and financial papers have been drawn upon with a free hand; these receive individual acknowledgment in the bibliography.

THEODORE J. HOOVER.

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CONCENTRATING ORES BY FLOTATION.

CHAPTER I.

Historical Sketch.

The ores of the base metals when taken from the earth contain the valuable portion in chemical combination, generally with sulphur, in the form of particles of metallic sulphide, mixed with a large quantity of worthless rock. The ore is first crushed to a suitable degree of fineness, in order to free the sulphide particles from the adhering gangue, and the crushed mass is then subjected to mechanical operations with a view to separating all the sulphide particles into one pile, and all the worthless gangue into another pile. The sulphides are then smelted to recover the metals. The oldest method of accomplishing this separation is by mixing the crushed ore with sufficient water to form a freely-flowing pulp and then subjecting the pulp to a shaking, throwing, and flowing motion, on suitable machines, whereby the sulphide particles, being much heavier than the gangue, travel faster and farther than the gangue, and are diverted at the proper time and place to effect a separation. This method is ancient, and was the only one known for hundreds of years.

A second method, introduced not long ago, made use of the magnetic qualities of the valuable minerals. These in general have a stronger magnetic permeability than the gangue, and if the ore is suitably subjected to the influence of powerful magnets, the valuable mineral particles can thereby be separated from the worthless gangue.

These two methods have limitations as to their usefulness, and these limitations have been a constant spur to metallurgists, urging them to the discovery of new modes of treatment.

The knowledge that substances heavier than water would, under suitable conditions, float on its surface is not at all new, the best known example being that of a greased needle carefully placed on water. It has been known also for many years that some heavy substances will float on the surface of water with more certainty than others, and the principles involved in this fact formed the basis of a third method of separating mineral sulphides from gangue as soon as it was recognized that the sulphides would float with greater facility than the gangue. The successful concentration of ores by causing the metallic sulphides to float at the surface of a liquid, and the gangue or waste rock to sink within, with entire disregard of relative specific gravities or magnetic qualities, has now not only overcome the suspicious novelty of its earlier phases, but has an established and growing position in the metallurgy of the base metals. The progress of the practical application of this principle has been so great during the past ten years as to place it now among the sure expedients of the metallurgist. To the minds of those who have had occasion to apply the process it seems almost as great an advance in the dressing of base-metal ores as the cyanide process proved to be in the recovery of the precious metals. In the recovery of zinc sulphides, especially from the by-products of lead milling, and also of finely disseminated copper sulphides from silicious gangues, it has already a wide field in instances where other methods were of imperfect application, and the range of its application is daily being widened.

A new metallurgical process never springs fully developed from the brain of one person, but is the result of patient investigation, application, and improvement by many minds, during many years. Metallurgical advances can best be likened to the construction of a pyramid by the constant addition of material. The erection of such structures can never be credited to a single person. The first stones are usually laid by those who had an imperfect vision of the structure that would arise, and while many builders come into prominence from year to year, many stones are laid by unknown hands. No builder need flatter himself he has completed the structure by placing a peak stone in place, for while he is in the very act, it is quite likely an ambitious newcomer has begun a dozen new courses of masonry at the base of the pyramid. Unfortunately, besides the question of individual credit, there also enters the more serious one of ownership to

parts of the structure. Constructive work may be entirely suspended while the courts adjudicate the rights of rival claimants; the completion of the structure is delayed; the time and means of the builders are wasted; and the needs of the industry suffer. The names of those who are known to have helped in this case are Haynes, Tunbridge, Miss Everson, Hebron, Bradford, Dodé, Sutton, Robson, Crowder, the Elmore brothers, Potter, Delprat, Van Meter, Boss, Haultain, Stovel, Froment, Scammell, Cattermole, Goyder, Laughton, Wolf, Sulman, Picard, Ballot, De Bavay, Darling, Gillies, Kirby, Macquisten, Sanders, Schwarz, Chapman, Kendall, Latimer, Hoover, Norris, Higgins, Lockwood, Samuel, Greenway, Horwood, Wentworth, Lavers, Nutter, Hyde, Hockley, Rouse, Maleczek, Allen, Wynne, Dick, Ruthenburg, McCourt, Orr, and Good.

Tardy justice demands that among those who builded better than they knew, the name of Carrie J. Everson, an American school-teacher, and an assayer and chemist of ability, should be specially mentioned, because she discovered and enunciated the main and fundamental principles upon which all subsequent work has been based.

The development of this important department of metallurgy can be divided roughly into three stages. During the first of these, 1860 to 1902, there were brought forward at least a dozen methods for causing sulphides to float on an ore-pulp, and these methods fell into two principal classes, although there were even then some patents which could not properly be placed in either class:—

(1). Those depending on the selective action of oily substances for sulphide particles to entrap the sulphides, and the buoyancy of the oily substance to effect flotation.

(2). Those depending on the selective action of gas for sulphide particles, and which under certain conditions endowed the particles with a gaseous envelope, and so induced flotation.

Neither of these ideas when used independently produced entirely satisfactory results, although they were not without some commercial profit.

The second stage, from 1902 to 1907, was marked by a practical advance when the idea was developed of endowing the particles with an oily coating in an acid solution, thus increasing their affinity for the gaseous envelope. This combination of the two

fundamental ideas of the preliminary stage has made it possible to secure a high degree of flotation among many sulphides. These two stages belong primarily to the inventor, the so-called unpractical man.

The third stage, 1907 to 1912, in which we now are, is the stage of the engineer : the commercial application of the idea. Suitable mechanical devices had to be invented to produce the proper mixture of gases, liquids, and solids, and to entrap the concentrate when afloat. This stage has now reached so practical a development as to find widespread commercial application.

The different processes have been developed along several lines parallel to each other, so that it is difficult to discuss them as a whole chronologically. They will, therefore, be considered separately in the order of their first appearance.

HAYNES.

William Haynes in 1860 invented a process for separating mineral sulphides from the gangue or rocky constituent of an ore by the use of oily, gummy, or bituminous matter. This was not a 'flotation' process, but must be considered the pioneer movement in that direction, as Haynes recognized the fact, all important in later developments, that oily substances have a greater affinity for sulphides and metals than they have for oxides and earthy substances. No commercial application of this invention is known to have been attempted.

BRADFORD.

Hezekiah Bradford, in 1886, invented a process of concentration based on 'surface tension' factors, but no commercial application of the idea is known to have resulted. His patent is an important and interesting one, because the flotation of sulphide particles on the surface of a liquid at rest is clearly set forth.

EVERSON.

Carrie J. Everson, in 1885, invented a process for separating the sulphides in an ore from the gangue. She made use of the selective action of the oil for sulphides, discovered by Haynes, but she also carried the idea two steps further. She discovered—(1) that acid, added in small quantity to the pulp, greatly increased the selective action of the oil ; and (2) that the oiled mineral could be separated from the gangue by giving the mass thorough agitation, and allowing the sulphides and the oil to float to the surface, while the

gangue escaped at the bottom of the vessel. The amount of oil used is variously stated in certain experiments as 6%, 12%, and 20%; the amount of acid was less than 1%. It is worthy of note that none of the quantities of oil specified are sufficient to effect the flotation of the sulphide contents of the ore by the buoyancy of the oil alone, and the flotation must, therefore, have been effected by some other means. The new principles disclosed in this patent were that acid increases the selective action of the oil, and that minerals can be separated from each other by allowing some to float and others to sink. Miss Everson stumbled across the idea quite accidentally.[1] Some sacks in which concentrate had been shipped to her brother's assay-office at Denver had become greasy, and in the process of washing the sacks, the germ of the idea of oil-flotation came under her observation. Attention should be directed to the fact that this invention is strictly feminine in its origin. No masculine assayer probably ever did or ever will launder sample-sacks or ore-bags; when they have reached the condition in which they need washing and where simple shaking does not make them available for further use, they are discarded. When she had the greasy concentrate-sacks in the wash-tub and gave them such agitation as was incident to the operation of washing, it only required the customary acuteness of observation of the Western lady school-teacher to grasp the essential facts of sulphide flotation. This process was tried on a fairly large scale at Baker City, Oregon, in 1889, and also near Denver in the same year. A capitalist by the name of Thomas F. Crilley financed the undertaking. In the process as tried at Baker City, under the name of the Crilley & Everson process, the ore was crushed to 50-mesh, weighed, and roughly mixed with a thick black oil. Boiling water, containing enough acid to give it a tart taste, was then added to the ore.[2] A thick scum of mineral and oil rose to the surface, and was skimmed off,[3] leaving the gangue at the bottom of the vessel.[4] This process was improved in 1892 by Hebron and Everson, whereby they combined pulverized ore with a buoy-stock in a dry state and then applied the prepared ore to a stratifying apparatus into which air

1 *Financial Times*, March 3, 1902.
2 *Eng. & Min. Jour.*, Nov. 15, 1890, p. 581.
3 *The Denver News*, Nov. 2, 1889, quotes a description from the *Herald-Democrat*.
4 *Alta Californian*, Dec. 2, 1889.

could be introduced for the purpose of producing effervescence.

The newspaper accounts of the attempts to apply this idea give one a strong impression that if the invention had been a less startling innovation it would probably have received more attention from engineers and metallurgists and the development of the idea would probably in that case have taken place many years before it did. The competition for ores and products was also less keen at this time than later and there was therefore not the incentive there is today to turn refractory ores to account.

No further definite commercial advance was made, and nothing more was heard of concentration by flotation until 1894.

ROBSON & CROWDER.

In 1894 Robson & Crowder invented a process for separating sulphides from gangue; they made use of the idea of oil-selection, but they did not recognize the benefit of acid in increasing this selective action, as Everson had done. Their invention differed from former similar ones in that they used but little water; they say, 25 to 30%. They mixed the ore and water in a vessel having a suitable agitator, added the oil at the bottom of the vessel during agitation, and allowed it to overflow. Presumably, after a time, the oil had selected and carried over all the sulphides, leaving the gangue, mixed with oil and water, in the bottom of the vessel, from which it could be drawn off. The process was tried at the Glasdir mine in Wales, on a fairly large scale. This mine was the place where Elmore later developed his idea of oil-flotation. In April, 1896, James Brothers made a careful examination of the plant and process for a client, and reported that the process was worthy of development, as it seemed adapted to a large class of ores at that time untreatable by other processes. Nothing material came of this effort, however, and the idea lay dormant until 1898, when F. E. Elmore advanced it apace.

ELMORE (OLD PROCESS).

Francis E. Elmore, in 1898, invented a concentration process that involved the idea of oil selection and the idea of flotation in a freely flowing acid pulp. He mixed the ore with several times its weight of water, and an equal, or several times greater weight of oil in a revolving drum,* so constructed and operated as to

**Trans. I.M. & M.*, Vol. VIII., p. 379–395, Chas. M. Rolker.

give a mixing effect without breaking up or emulsifying the oil, which was added with the ore. He did not mention the amount of oil used, but from the fact that he described in his patent a pump for the oil and a centrifugal apparatus for separating the concentrate from the oil, it is inferred that the amount of oil used was considerable. After thus gently mixing, the mass was allowed to run into a spitzkasten, where the oil carried the sulphides to the surface, and the gangue and the water were removed from the bottom. This invention marks a decided advancement in flotation-concentration, and was put into operation in a workmanlike manner.

The process had commercial application on a large scale. It was in the hands of capable engineers, who were not oblivious to its imperfections, and who appreciated that no one process is ever a cure for all the troubles incidental to the treatment of ores. They tried consistently to adapt the process to suitable ores, and where they made mistakes these were only such as must be made when development along new lines is attempted. This process was the first of the kind to approach commercial success, and it was a commercial success in many places ; but further improvements in flotation concentration have rendered the method obsolete.

The process was tried by the Boston Consolidated Co., Cape Copper Co., and Namaqua Copper Co.[1] The United States rights were[2] purchased by Charles Butters, who tried it on the ore of the Mammoth Mining Co., Utah.[3] Companies were organized in Canada,[4] Great Britain, Sweden, Australia,[5] and plants were built in Norway, England, and in British Columbia on the Le Roi mine. The Le Roi plant had a long series of vicissitudes, and was finally closed down.[6] Plants were built at Tywarnhaile[7] in Cornwall, at the Sygun mine in Wales,[8] and at the St. David's mine in Wales.[9] In 1903,[10] the firms of S. Neumann & Co. and

1 *Eng. & Min. Jour.*, Sept. 1, 1900, p. 241.
2 *Eng. & Min. Jour.*, Dec. 8, 1900, p. 661.
3 *Eng. & Min. Jour.*, June 29, 1901, p. 836.
4 *Eng. & Min. Jour.*, July 5, 1902, p. 308.
5 *Mineral Industry*, Vol. XI., p. 656.
6 *Eng. & Min. Jour.*, Jan. 5, 1905, p. 160.
7 *Mineral Industry*, Vol. XI., p. 698–707.
8 *Eng. & Min. Jour.*, Jan. 17, 1903, p. 134.
9 *Eng. & Min. Jour.*, Feb. 14, 1903, p. 262.
10 *Eng. & Min. Jour.*, July 25, 1903, p. 136.

Wernher, Beit & Co. purchased a quarter interest in the rights for the whole world, and prepared to push the development and application of the process. The year 1905 may be said to close the activities of the old Elmore process, as most of the plants were either closed down entirely or modified for what is now known as the Elmore vacuum process.

VAN METER AND BOSS.

James W. Van Meter and Martin P. Boss in 1902 invented an oil process, which was installed[1] at the Santa Barbara mine and also by the Alpimina Mining Co., both in Peru. This process was similar to the Everson process and the old Elmore process in its main principles, but the apparatus was somewhat different. Though the published results were good, the process has disappeared from the field of concentration in consequence of further developments.

POTTER-DELPRAT.

Charles V. Potter in 1902 invented a process of mineral flotation wherein the flotation was accomplished in a 1 to 10% solution of acid. He added one ton of this solution to one ton of ore, agitated freely, and applied heat. As the temperature of the pulp increased, the heat caused the sulphides to rise to the surface, from which they were allowed to flow continuously or were skimmed off. Potter did not mention the use of any gas, but it is clear that he had in view a surface-tension process. In 1902 there had been rumours at Broken Hill[2] that a new process along radically new lines had been discovered at the Proprietary mine. This was especially interesting, as there were in the district several million tons of crushed material that had hitherto defied treatment. The rumour proved to be true, and later was announced as the Delprat or salt-cake process. The priority of patent, however, fell to Charles V. Potter, who had been working on similar lines to Guillaume D. Delprat. Potter used an acid liquor to effect flotation, while Delprat accomplished the same result in the same way with acid salt-cake solution. The effect of the acid or salt-cake is to generate bubbles of gas, which selectively adhere to the sulphides and float them. Potter and Delprat invented improvements from time to time subsequently, and their most recent patents indicate that the owners of these processes appre-

1 *Pacific Coast Miner*, May 30, 1903, p. 391.
2 *Ann. Rep. Dept. of Mines*, N.S.W., 1902, p. 69.

ciate that a small quantity of oil is of decided advantage to flotation. The Potter process received its chief application at the Block 14 mine at Broken Hill, in 1905 and 1906, where it had a measure of success on sharp sand, the attempt to treat slime being attended with many difficulties; the plant is now dismantled. It was also tried at the Zinc Corporation's plant, where it was pronounced a failure. The Delprat process is installed at the Broken Hill Proprietary mine, where it is a decided success, and produces about 80,000 tons of zinc concentrate per year. This plant is the third largest flotation-concentration plant in the world, treating about 1,000 tons per day, and it is a pity that a policy of secrecy as to its later developments is thought necessary. The Potter and Delprat interests soon became involved in litigation, ending in a compromise, so that the process is now generally described as the Potter-Delprat.

FROMENT.

In 1901 Alcide Froment, of Traversella, Italy, discovered that when a sulphide ore is agitated in water in the presence of a small quantity of oil and sulphuric acid, the sulphide particles become oiled and attach themselves to and are floated by gas bubbles. He recommended adding a small amount of calcite to ores when needed. This discovery is of the greatest importance, as the successful development of oil-flotation processes has been based principally upon making use of the fact that oiled sulphide particles readily attach themselves to, and are floated by, gas bubbles. Minerals Separation Ltd. bought this patent in November, 1903.

MINERALS SEPARATION.

In 1903 a company was organized by John Ballot, J. H. Curle, W. W. Webster, S. Gregory, H. L. Sulman, and H. F. K. Picard, all of whom had for many years been interested in ore-treatment problems. The original purpose of this company — Minerals Separation, Ltd.—was to acquire and operate the Cattermole patents. Soon after organizing, they purchased the Froment patents, and from time to time since then they have invented improvements and additions. Their present processes are based on surface-tension phenomena, accelerated by means of the addition to the pulp of very small quantities of oil and of air in a fine state of subdivision, the purpose of the oil being to coat the

sulphides with a thin film of oil, and the purpose of the air being to adhere to the oiled mineral particles, and to raise them to the surface in the form of a froth.

The Cattermole invention was a process of ore concentration in which use was made of the idea of oil selection. He added to a freely flowing pulp from 4 to 6% of oil in proportion to the sulphide contents and also to the pulp, 2% of soap, the amount depending on the metallic contents of the ore, the object being to produce granules of sulphides of a definite size, or in other words, coagulation of the sulphides. For slimy ores he added a portion of coarser sulphide particles to serve as nuclei for the formation of granules, and effected the separation by an upcast current of water, taking the gangue off the top and the granules at the bottom. Another of this company's inventions was by Sulman & Picard in 1903, a process of oil concentration in which they introduced bubbles of air or other gas, and also oil in the form of a spray, into the freely flowing acidulated pulp. This invention follows Froment and Cattermole in its main lines, but is novel in the methods of introducing the oil, and in the method of the introduction of air into the slightly oiled pulp. The best development of this series was the introduction, in 1905, of a method which I am informed by their solicitor has recently been denominated by the Minerals Separation, Ltd., as the 'agitation-froth process,' a method of flotation in which an extremely small amount of oil, less than 0.1%, was added to a freely flowing pulp, followed by violent agitation for from 1 to 10 minutes. Innumerable small bubbles of air were thus mechanically included in the pulp, which joined the oil-coated mineral particles by means of the surface tension of bubbles, and floated them in the form of a froth, which was separated in a spitzkasten. The tailing from the spitzkasten was then exposed to the air as it flowed over an inclined surface, and any oiled mineral that had escaped coming in contact with air-bubbles there took up its proper air-film and floated as a film on a second spitzkasten. Other improvements in this company's method and apparatus have been made from time to time, the most important of which was the Hoover apparatus.

The first plant using this process was erected in Australia, on the Central mine at Broken Hill, to treat an accumulation of zinkiferous tailing from the Sulphide Corporation's lead-concentrating mill. It had a capacity of 400 tons per day. This plant

ran two years with an average of 72 per cent. recovery of the zinc in the form of a high-grade concentrate. The Sulphide Corporation then built a second plant, as part of a new concentrating mill, to take the current tailing from the lead concentrators, and thus has a complete mill, turning out lead concentrate by ordinary tables, and zinc concentrate by the Minerals Separation process in one continuous operation. This plant has a capacity of 900 tons per day. The Minerals Separation, Ltd., purchased the remainder of the Central mine's accumulated zinkiferous mill-tailing, and erected a third plant for the treatment of this material by their own process. This plant had a capacity of 900 tons per day. When the two last-mentioned plants were in successful operation the first plant was abandoned, being antiquated by virtue of later improvements. A fourth plant for the use of this process on an accumulation of zinkiferous and plumbiferous slime from the Block 10 and Central mines was then erected. Nearly all this material was fine enough to pass a 100-mesh screen. No difficulty was encountered in producing a pure mixed lead and zinc sulphide from this material, but the smelting of the concentrate presented such difficulty that the operation of the plant was discontinued. Recent developments in both the art of smelting zinkiferous concentrate and also in the methods of flotation-concentration warrant the belief that this slime-plant can now operate at a profit.

This process was, among others, tried by the Zinc Corporation in its early struggles, but for some reason it was impossible to get the results that were being obtained on the Central mine. Thereupon the process was discarded in 1907 in favour of the Elmore vacuum process, which was in use profitably for two years. Then in 1910, owing to the exhaustion of the material treatable by this process and to decided improvements in the apparatus for the Minerals Separation process, the Elmore process was discarded and the Minerals Separation process installed.

This process was tried in South Russia, at the Caucasus Copper mine, on a small scale, but although the trials were favourable, the company did not see fit to give it an extended application.

A unit having a capacity of 250 tons per day was installed at the Great Fitzroy mine, Queensland, and after extended trials and being several times re-modelled, now seems in a fair way toward commercial success.

On the Orijarvi* mine, in Finland, a small unit of this process was installed, but is not now in use.

**Eng. & Min. Jour.*, Vol. XCI., 1911, p. 759.

A small plant was also built at the Emu Works, Swansea, for a trial of the San Francisco del Oro ore, but the attempt was not a commercial success, because of the excessive acid consumption. Recent developments indicate that possibly this ore can be treated by the use of sodium bisulphate and other reagents.

The Junction North mine, at Broken Hill, is installing a plant designed to treat slime mixed with crushed crude ore from the mine.

A large plant has recently been erected on the Braden copper mine for the treatment of a copper ore which had hitherto given considerable trouble. The plant is a large one and the results are excellent.

GOYDER & LAUGHTON.

Goyder & Laughton, in 1903, invented a machine which employed Potter's idea of adding the ore to an acid solution. They were the first to disclose the principle governing Potter's and Delprat's acid-flotation processes, namely, that the action of the acid on the ore generated gas-bubbles to which the sulphide particles attached themselves and were floated to the surface. One of the difficulties of the acid-flotation process was that the bubbles broke on reaching the surface, and the mineral particles sank again, that is, the surface tension was not strong enough to hold them up under the conditions to which the particles were exposed for flotation. This invention not only seeks to obviate a bad feature of the acid-flotation process, but in a measure takes advantage of it. The machine was tried in several plants at Broken Hill, but is not now in use.

WOLF.

Jacob D. Wolf, in 1903, invented a method of applying the principles of flotation. He used sulpho-chlorinated oil, or any other oil, and aimed to secure a high degree of mineral extraction with a low grade of concentrate in the first step, and by washing the concentrate with hot water in a suitable vessel to increase the grade of concentrate in the second step. As another feature in his process, air or steam was blown into the tailing, which raised to the surface globules of lost oil, with sulphides adhering thereto, thus increasing the percentage of extraction. This patent contains several ingenious devices, but no practical application of the invention has so far been made.

ELMORE (NEW VACUUM PROCESS).

In 1904, Francis E. Elmore took out a patent for an apparatus and process wherein he secured flotation in the form of a mineral froth by the addition of a small quantity of oil, and by the liberation of the air in the pulp in a fine state of subdivision, the liberation of the air being accomplished by subjecting the freely flowing pulp to a vacuum, and by heating, whereupon the air which is dissolved in the pulp, amounting to 2.2% by volume, at normal temperature and pressure, is released and attaches itself to the slightly oiled mineral particles, raising them to the surface. This process is performed in a machine of rather complicated design, having a capacity of 20 to 50 tons per day, depending on the nature of the ore. A battery of these is operated with comparative ease after the men have become accustomed to the different adjustments. This process had its most noted application at Sulitelma in Norway, and also at the Zinc Corporation's plant* at Broken Hill, where it proved a decided success. This last-mentioned plant had 16 units in operation, producing 75,000 tons of concentrate per year. The concentrate was retreated by burning off the oil and then passing it over Wilfley tables to remove some of the lead. This process has been replaced by the Minerals Separation process.† The British Broken Hill Proprietary mine has a battery of 10 vacuum machines in operation.

The Elmore vacuum process has also been installed at Dolcoath, Ramsley, and Dolgelly, in Great Britain,‡ at the Garpensberg, Traag, Hadeland, Sulitelma, Telemarken, and Saxberget mines in Scandinavia, and at the Edmundian mine in Africa. It has been installed, but it is not working at the present time, at the Pinnacles mine and the Cobar gold mines in New South Wales, the Namaqua copper mine in South Africa, the Caucasus copper mine in Russia, at the Avino mine in Mexico, and elsewhere.

DE BAVAY.

Auguste J. F. De Bavay, in 1904, invented a flotation process in which a thin film of freely-flowing pulp was brought to the surface of a vessel of water where advantage was taken of the surface

Eng. & Min. Jour., Vol. LXXXVIII., June 1, 1909, p. 205.
†*Eng. & Min. Jour.*, Vol. XCI., June 1, 1911, p. 1,198.
‡*Eng. & Min. Jour.*, Vol. LXXXIII., June 1, 1907, p. 1,037.

tension of the liquid, and the sulphide floated. He further points out that if the surface of the sulphide particles is coated with a film of carbonate from weathering, this is detrimental to the process, and should be removed by soaking the ore in a weak solution of carbonate of ammonia, or by passing carbonic acid gas through the pulverized wet ore, or by friction.

His process was installed at the Broken Hill North mine in 1905, and was there a success. His plant and methods have undergone many changes, and he is now using a small quantity of oil to enhance the extraction. He first washes the tailing free from slime, and then adds a small amount of oil to the clean sand, with agitation, and separates the scum or film of mineral sulphides in a spitzkasten. A new mill having a capacity of 1,600 tons per day was started in 1910 on the dumps from the Block 10 mine, combined with the current slime-free tailing of the North and South mines. This is the largest flotation-concentration plant. The venture was brought out as the Amalgamated Zinc (De Bavay's) Ltd., which corporation also owned the exclusive right to use this process at Broken Hill, the patent rights for the rest of the world being retained by the De Bavay Treatment Co. These companies have not published any comprehensible statements of cost and treatment, and little is known about the methods they use.

GILLIES.

In 1906, James H. Gillies' patents were applied on a commercial scale at the Block 10 mine, Broken Hill, N.S.W. Gillies' apparatus seems to be unique; his processes were based on the principles of Potter and Delprat, but later he made use of the principles described in the Minerals Separation patents. The plant was a failure economically, and has been abandoned.

MACQUISTEN.

Arthur P. S. Macquisten, in 1904, invented a process and a tube apparatus therefor which made use of the surface tension of liquids for separating minerals, whereby some floated and others sank. His apparatus is new and important, but works on the old and well known principle of surface tension. In 1906 this was applied on a working scale in the Adelaide Reduction Works, at Golconda, Nevada. The process, like all the flotation processes except the Minerals Separation and Potter-Delprat, has

difficulty in handling slime.* The plant consists of 100 tubes, and the capacity is 125 tons per day. The latest development of this idea is the introduction of oil to the process, thus bringing it pretty much on a par with all the others as to the principles involved.

In 1911, the Federal Mining & Smelting Co. installed 119 of these tubes at the Morning mill at Mullen, Idaho, for the treatment of a middling product containing blende, galena, siderite, and quartz, but the results are not entirely satisfactory. The capacity is about 150 tons per day.

MUREX.

Lockwood & Samuel, in 1908, invented a process for making sulphide particles more magnetic by utilizing the selective action of oil, and in 1909 described a method of increasing the selective action of oil by treating it with various soluble salts ; also a process where magnetic or magnetizable substances are added to an ore-pulp, the whole being then treated with an oil to cause the sulphides and the magnetic particles to adhere together, and then removing them from the pulp by means of a magnet. Although this is not a flotation process, it makes use of some of the principles involved, and is in some respects similar. Two units have been installed and are successfully working at Cordoba, in Spain. A plant erected at Broken Hill on the Block 14 mine has, however, had many vicissitudes ; it has been closed down as unadapted for the work, and moved recently to the Amalgamated Zinc works.

Plants have been sent to Bolivia to a mine belonging to Aramayo, Francke, & Co., and to the Malines mine in France.

ZINC CORPORATION.

This is a company organized in 1905 to work the accumulation of zinky tailing in the Broken Hill district. The company purchased in all more than 4,000,000 tons of tailing and slime from different mines in the district.

The company did not own any process, but the history of the company has been so closely allied to the development of this branch of the art that it is quite proper to give a brief sketch of it. The company first tried the Potter process. A plant was built in 1905 at the British Broken Hill Proprietary

Mineral Industry, Vol. xv.. p. 776.

mine, and was intended to have a capacity of 400 tons per day. After extended trials and expensive alterations, the Potter idea was abandoned as not practical.

In 1907 this plant was entirely re-modelled to install the Minerals Separation process. This process had been used for some time satisfactorily on the Central mine near by, but in the Zinc Corporation plant this process was also abandoned as not satisfactory.

Extended trials had been made in the meantime, under the management of D. P. Mitchell, with the new Elmore vacuum-concentration process. These trials had been most successful. It was decided, therefore, to move the scene of operations and build a new mill where better crushing facilities could be provided. This mill was built in 1907 and 1908 near the southern end of the Broken Hill district, and 16 Elmore units were installed. This process was a success, and ran for two years at a handsome profit.

Then, in 1910, owing to improvements in the apparatus for the Minerals Separation process, and owing also to the depletion of supplies of material suitable to the Elmore process, the Minerals Separation process was again adopted. The Elmore units were taken out and the Minerals Separation process has now been operating on both sand and slime at a good profit for nearly two years.

The most recent step in the history of the Zinc Corporation is the amalgamation of that corporation with the Broken Hill South Blocks, Ltd., which gives the combined business, besides the excellent equipment of the Zinc Corporation and the enormous tonnage of purchased tailing, the advantage of the continuous supply of ore from the South Blocks mine.

HYDE.

In 1911 James M. Hyde invented and patented a flotation process in which a small amount of sulphuric acid, with or without the use of copperas (iron sulphate), is used to give the slimy portion of the ore a preliminary coagulation before bringing it to the flotation machine, and in which the sulphides, after agitation, are floated off rapidly and as completely as possible, with a considerable overflow of freely-flowing water, thereby producing an impure concentrate which is re-treated in a second machine, from which only high-grade concentrate is taken off, with no freely-flowing water. The

process has been adopted by the Butte & Superior Copper Company of Butte, Montana, in their new 500-ton zinc mill which is shortly to be increased to a capacity of 1,000 tons per day. The process is giving highly satisfactory results. This is the first attempt to use a flotation process on a large scale in the United States.

The recent amalgamation of the patent interests of the Amalgamated Zinc, Ltd., and the Minerals Separation, Ltd., in Australia, is a step in the right direction, as it will stop litigation already begun, and prevent more that was threatened. The De Bavay patent rights for the rest of the world are now owned by Minerals Separation, Ltd. The patents now included under the one group are those of Froment, Potter, Delprat, Cattermole, Sulman, Picard, Ballot, De Bavay, Goyder, Laughton, Higgins, Greenway, Chapman, Lavers, Nutter, and Hoover.

A much clearer idea of the evolution of the processes can be secured from a summary of the patents in chronological order, which is given in the next chapter. Some repetition will be necessary, but the history of metallurgical devices is largely a recital of alterations and experiments.

CHAPTER II.

PATENTS.

In this analysis the intention is to set forth the flotation patents as they appeared from time to time, from 1860 to 1912, and to paraphrase and explain the meaning of them in language somewhat simpler than the legal phraseology of the patent. As the development of these processes has taken place mainly in Great Britain and the Colonies, the records of the English Patent Office have been followed as to dates, although those of the United States and other countries present some exception to strict chronology.

A careful search of the records of the patent offices of Great Britain and the United States reveals nothing prior to the year 1860 that in any way bears upon the subject of concentration by flotation.

EXPIRED PATENTS.

William Haynes, in British patent No. 488, February 23, 1860, described a process for separating mineral sulphides from the gangue or rocky constituent of an ore by the use of oily, gummy, or bituminous matter. This was not a flotation process, but must be considered the pioneer movement in that direction. The process described in the patent is as follows :

1. The ore is ground to the requisite fineness.

2. An agent, which may be a fat or an oil, alone or in combination with other things, is added to the crushed ore in the proportion of one part of agent to five or nine of ore.

3. The agent and ore are mixed or agitated in a proper machine.

4. Sufficient water, preferably warm, to cover the whole is added to the agitated and mixed mass.

5. The water and mixed mass of ore and agent are passed through a proper triturating machine, by which operation the combined sulphides and agent alone remain in union, while the earthy matter or gangue of the ore sinks to the bottom of the water.

The central idea of this invention is the separation in a triturating machine of sulphides from gangue by means of the selective adhesion of oils for sulphides.

JOHN TUNBRIDGE, in United States patent No. 228,004, Nov. 4, 1879, described a process for recovering finely comminuted metal held in suspension in water by the use of soap or a saponaceous compound. This patent is just nearly enough related to the subject matter of this discussion to be mentioned for the sake of completeness.

HEZEKIAH BRADFORD, in United States patent No. 345,951, June 22, 1885, described a process for separating sulphides from gangue by what is clearly the first well defined surface-tension flotation process.

For the treatment of wet tailing from tables, vanners, and jigs, one method is described, but for the treatment of dry crushed ore it is specified that the dry ore is to be sprinkled on the surface of water with as little concussion as possible, and from this point the treatment is obviously the same as with wet tailing.

In its simplest form the apparatus prescribed takes the tailing, mixed with water from some previous operation, at a point say *b* (Fig. 1), which may be a moving portion of a shaking table. By means of an adjustable lip *b′*, the pulp is transferred to an inclined plane *a*, in passing over which the sulphide particles become exposed to the air, and the force of the surface tension of the

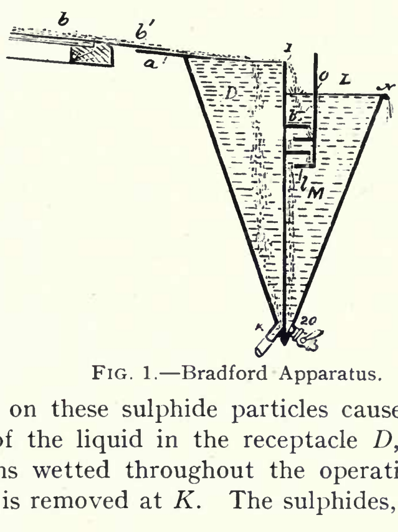


FIG. 1.—Bradford Apparatus.

liquid acting on these sulphide particles causes them to float on the surface of the liquid in the receptacle *D*, while the gangue, which remains wetted throughout the operation, sinks in receptacle *D*, and is removed at *K*. The sulphides, on the other hand,

which are floating at the surface of receptacle *D*, float across the receptacle to the lip *I*, and plunge into the liquid contained in receptacle *L*. The baffles *l* arrest the fall of the sulphides and assist them to become wetted, so that the force of surface tension no longer acts on them, and they sink quietly to the bottom of receptacle *M* and are removed at 20, while the superfluous water passes over the lip *N*.

The central idea of this invention is the separation of sulphides from gangue by flotation of the sulphides at the surface of a freely flowing ore-pulp through the action of the force of surface tension of the liquid.

Carrie J. Everson, in United States patent No. 348,157, Aug. 29, 1885, described a process for separating the sulphides in an ore from the gangue. The patent describes two distinct processes, the first of which is analogous to that of Haynes. The main improvement made by this first Everson process over that of Haynes is the discovery that acids increase the selective adhesion of oils for sulphide particles.

The second method Everson described is a flotation process pure and simple, and is of interest :—

(1). The oil should desirably be first mixed with the ore.

(2). Water containing a suitable amount of free acid in quantity ample for the operation to follow is added to the mixed ore and oil.

(3). Thorough agitation of the mass.

(4). Removal of the concentrate by flotation and a constant overflow of water from the washing-out vessel.

(5). The gangue being heavier, the inventor says, than the mixed oil and sulphides, sinks to the bottom of the washing-out vessel and can be removed there.

The central idea of this invention is the separation of sulphides from gangue by flotation of the sulphides at the surface of the liquid in a vessel, this flotation being accomplished through the agency of the forces brought to bear on the ore-pulp by the addition of oil and acid, and by thorough agitation.

Edward Dodé, in British patent No. 14,357, Sept. 11, 1889, described a process that refers to the separation of metallic gold, silver, etc., from other metals by first dissolving them in acid solution and then treating them with oily substances. The patent is just nearly enough related to the subject matter of this discussion to be mentioned for the sake of completeness.

Hebron & Everson, in United States patent No. 471,174, Sept. 1, 1891, described a process wherein they mixed a 'buoy-stock' with the ore. This process is in the main similar to Everson's, and has some remarkable affinities with Bradford's, but there is some radical departure from previous patents.

The essential feature of the invention consists in submitting the ore and the buoy-stock to a rubbing movement so that the particles of buoyant material are pressed into the cavities and pores of the mineral and made to adhere to the rough and irregular surfaces thereof, so that the joined mineral and buoyant material are of less specific gravity than the rock particles of the ore.

Charles B. Hebron, in United States patent No. 474,829, July 22, 1891, describes an improvement to the Hebron & Everson invention, which consists in subjecting the mixed ore and 'buoy-stock' to a vacuum and heat, thus greatly increasing the efficiency of the 'buoy-stock.' This patent is built upon the foregoing one, but emphasizes two important points:

(1). The buoyant material is more advantageously added to the ore hot, in a vacuum, as in that case the buoyant material comes into closer union and is more intimately joined to the metallic or sulphide particles.

(2). After the buoyant material has been mixed with the ore in a vacuum, the ore must be thoroughly aerated by blowing air through the mass.

The prepared ore was then submitted to a flotation treatment, substantially the same as that described in Hebron & Everson, where the addition of air to the operation and effervescence of the liquid are recommended.

Edgar A. Hockley, in United States patent No. 466,753, Jan. 5, 1892, described an invention whereby particles of metal or mineral may be recovered by flotation aided by the introduction of air.

Albion M. Rouse, in United States patent No. 469,599, Feb. 23, 1892, described a method of creating a froth or foam of matter foreign to water and the recovery thereof.

Maleczek, in New South Wales patent No. 3823, of the year 1892, described a frothing process, wherein as a result of treating the ore with salt solution in hot oil the sulphides were floated to the surface, presumably through the agency of air or other bubbles, and floated as a froth.

Joseph William Sutton, in British patent No. 24,144, Dec.

31, 1892, described a process for recovering gold from its solution by means of flotation with oils in an acidified liquor. This patent is just nearly enough related to the subject matter of this discussion to be mentioned for the sake of completeness.

JOSEPH WILLIAM SUTTON, in United States patent No. 521,899, Dec. 28, 1892, duplicated his British patent No. 24,144, Dec. 31, 1892.

HENRY LIVINGSTONE SULMAN, in British patent No. 24,939, Dec. 28, 1893, described a process for preventing the loss of 'float' gold in milling operations, by adding certain substances that cause it to sink by diminishing the surface-tension of the liquid. This patent is just nearly enough related to the subject matter of this discussion to be mentioned for the sake of completeness.

ROBSON & CROWDER, in British patent No. 427, Jan. 8, 1894, described a process for separating sulphides from gangue. This invention made use of the idea that oils have a selective adhesion for sulphides, but it differs from the previous inventions in that no acid and no air was used in the operation.

(1). The crushed ore, if not already in a proper state, was first moistened with water.

(2). The moistened ore was then mixed with a large volume of oil with constant stirring and the continuous addition of oil.

(3). The sulphide particles were thereby floated away over the lip of the vessel by the constant overflow of oil.

This process does not seem to be much of an advance in the art. There have been some recent patents of a similar kind describing processes for separating mixed sulphides, but they are of doubtful utility. As this patent departs from the progressive line of development indicated by previous patents, and also because the line it takes has come to no commercial application, it is not necessary to consider it further, but it is here mentioned for the sake of completeness.

JOHN HENRY MCCOY, in United States patent No. 577,825, Feb. 11, 1895, described an invention for introducing air into a pointed box, for the purpose of separating particles. This is not a flotation process, but is mentioned for the sake of completeness.

UNEXPIRED PATENTS.

FRANCIS EDWARD ELMORE, in British patent No. 21,948, Oct. 18, 1898, described a flotation process that involved the idea of

oil-selection and the idea of oil-buoyancy flotation. He mixed the ore with several times its weight of water, and an equal or several times greater weight of oil in a revolving drum, so constructed and operated as to give a mixing effect without breaking up or emulsifying the oil, which was added with the ore. After thus gently mixing, the mass was allowed to run into a spitzkasten, where the oil carried the sulphides to the surface, and the gangue and water were removed from the bottom. This patent marks a decided advancement in flotation-concentration ; it was the first process of the kind to approach commercial success.

Francis Edward Elmore, in United States patent No. 653,340, April 10, 1899, duplicated in the main his apparatus in the British patent just described.

Francis Edward Elmore, in United States patent No. 676,679, April 10, 1899, duplicated his process described in British patent No. 21,948, Oct. 18, 1898.

Alexander Stanley Elmore, in British patent No. 6,519, Mar. 28, 1901, described a method of increasing the selective action of oil by adding acid to the pulp.

Alexander Stanley Elmore, in United States patent No. 689,070, April 13, 1901, duplicated the process described in British patent No. 6,519, Mar. 28, 1901.

Edmund L. Van Der Naillen, in United States patent No. 737,533, June 20, 1901, described an apparatus for ore concentration having a horizontal section decreasing in area upward. This patent is of limited interest.

John Klein, in United States patent No. 696,739, July 12, 1901, described a machine to which air was introduced for the purpose of carrying a portion of the ore off the top of the liquid and allowing the balance to sink. This is a patent of limited interest in this discussion.

Alexander Stanley Elmore, in British patent No. 15,526, July 31, 1901, described two forms of apparatus for conducting the processes previously patented by Francis E. Elmore. One form was designed to effect the separation of sulphides from the gangue by oil-buoyancy flotation, and differs little in principle from the apparatus described by Francis E. Elmore in his original patent. The other form of apparatus described is intended to effect the separation by a sort of oil-amalgamation, in which the oiled pulp flowed under and in contact with an oiled or greased canvas belt, which carried the oil and oiled mineral out of the

pulp. This patent is of interest in that the latter process therein described is extensively used at Kimberley, in South Africa, to separate diamonds from the 'blue ground.'

ALEXANDER STANLEY ELMORE, in United States patent No. 692,643, Aug. 8, 1901, duplicated the apparatus described in British patent No. 6,519, Mar. 28, 1901.

ALEXANDER STANLEY ELMORE, in United States patent No. 703,905, Aug. 8, 1901, duplicated British patent No. 15,526, July 31, 1901.

CHARLES VINCENT POTTER, in United States patent No. 776,145, Jan. 14, 1902, duplicated his British patent No. 1,146, Jan. 15, 1902.

CHARLES VINCENT POTTER, in British patent No. 1,146, Jan. 15, 1902, described a process of mineral flotation wherein the flotation was accomplished in a 1 to 10% acid solution. He added one ton of this solution to one ton of ore, agitated freely, and applied heat. As the temperature of the pulp increased, the heat caused, he says, the sulphides to rise to the surface, from which they were allowed to flow continuously or were skimmed. This patent deserves honourable mention, as it led to the recent decided development in flotation methods. Potter did not mention the use of any gas, but it is clear that he had in view a gas-bubble process.

HAULTAIN & STOVEL, in British patent No. 9,521, April 24, 1902, described a machine of the familiar Frue-vanner type, in which the concentrating belt was made of canvas, and was coated with a layer of thick oil. They thus took advantage of the well known specific gravity separation, and combined with it the principles of oil-selection. They separated the concentrate from the oil in hot water, when the oil, becoming fluid, rose to the surface, and the sulphides remained at the bottom.

CHARLES W. MERRILL, in United States patent No. 728,487, May 12, 1902, described a concentrating apparatus with a horizontal section decreasing upward. This patent is of just sufficient interest to be mentioned for the sake of completeness.

ALCIDE FROMENT, in British patent No. 12,778, June 4, 1902, described a flotation process that involved the use of oil, and also of a gas. He recognized clearly the important principle, which is emphasized in later developments, that when ore, water, oil, acid, and a gas are mixed and agitated together in the proper proportions, the oil not only has a selective action for the sul-

phides, but the gas also has a selective action for the oiled particles, and it is not necessary to have a large amount of oil present to float the sulphides by oil-buoyancy. He mixed the ore with three times its weight of water, and added a small quantity of oil. If there was no gas-forming mineral in the ore, a little limestone was added, and then also a small quantity of acid, which generated carbon dioxide in the pulp. He then agitated freely. He says the oiled mineral particles collected in spherules and were carried to the surface by the gas bubbles. Finally, he enunciates this important principle: 'The rapidity of the formation of the spherules and their ascension is in direct ratio to the quantity of gas produced in the pulp in a given time.' This patent was taken out only in Great Britain and Italy.

Joseph Barton Scammell, in British patent No. 15,280, July 9, 1902, described a method of thickening oils by the addition of sulphur chloride in order to increase the buoyancy of the oil and so increase the efficiency of the oil-buoyancy flotation processes. He agitated the ore, water, and sulpho-chlorinated oil in a suitable vessel, transferred the mass to settling-pans, and after a time skimmed the oil with the sulphides.

Guillaume Daniel Delprat, in British patent No. 26,279, Nov. 28, 1902, described a process of flotation that consisted in immersing the ore in a hot but not boiling solution (of specific gravity 1.4) of salt-cake, or a solution (of specific gravity 1.4) of sodium sulphate and sulphuric acid. The ratio of sodium sulphate to sulphuric acid was 2.5 : 1. The sulphides in the ore, he says, floated at the surface and were removed by a stream of water or by skimming.

Arthur Edward Cattermole, in British patent No. 26,295, Nov. 28, 1902, described a process of oil-concentration in which he made use of the idea of oil-selection. His method of procedure is not made plain in his patent, but seems to be about as follows: To a freely flowing pulp he added from 4 to 6% of oil, and 2% of soap, the amount depending on the metallic contents of the ore, his object being to produce granules of sulphides of a certain size. For slimy ores he added a portion of coarser sulphide particles to serve as nuclei for the formation of granules, and effected the separation by an upcast current of water, taking the gangue off the top, and the granules at the bottom. For ores containing small amounts of mineral he added a portion of oiled pumice or oiled charcoal to serve as nuclei and removed the granules so made

by flotation. After the concentrate had been secured, the oil was recovered by treating the oiled sulphides with an alkali, thus dissolving the oil and making it available for use again.

ARTHUR EDWARD CATTERMOLE, in British patent No. 26,296, Nov. 28, 1902, described a process of classifying mixed sulphides after they had been removed from an ore by his oil-granules concentration process. He accomplished this classification of sulphides by fractionally dissolving the oil of the granules in alkaline emulsifying agents of varying strength and activity. He first added to the oiled concentrate, with agitation, an alkaline solution that had a strength just sufficient to dissolve the oil from the sulphides having the least adhesiveness for the oil. This sulphide of least adhesiveness for oil was freed from the mixed sulphide granules, and was removed by an upcast of water or other suitable device. An alkaline solution of greater strength was then added to the remaining portion, with agitation, and the oil was dissolved from the sulphide having the next second adhesiveness for oil. This second sulphide was released in the same way as the first ; and so the process was repeated as often as was necessary.

GUILLAUME DANIEL DELPRAT, in United States patent No. 735,071, Jan. 2, 1903, described a process whereby flotation of sulphides is secured in a nitric acid solution.

GUILLAUME DANIEL DELPRAT, in United States patent No. 768,035, Jan. 2, 1903, duplicated British patent No. 26,279, Nov. 28, 1902.

ALEXANDER STANLEY ELMORE, in British patent No. 184, Jan. 3, 1903, described an improved apparatus for oil-concentration wherein air was excluded from the operation. His method was substantially the same as that described in his previous patent, and that of Francis E. Elmore, except that by sealing all open vessels with a ring or surface of oil, the operation was performed in such a manner as to prevent the introduction of air into the pulp and thus prevent the possibility of oxidation of the minerals. He also describes two methods of removing the concentrate from the oil, one by heat and one by filter-press treatment. He calls attention to the necessity of cooling the oil after heating, presumably for the purpose of maintaining its viscosity and to prevent emulsification.

JOSEPH BARTON SCAMMELL, in United States patent No. 770,659 Jan. 31, 1903, duplicated his British patent No. 15,280, July 9, 1902.

GUILLAUME DANIEL DELPRAT, in United States patent No. 763,662, Mar. 9, 1903, described a new form of apparatus for the application of his processes described in United States patents Nos. 735,071 and 768,035, Jan. 2, 1903.

HENRY A. ALLEN, in United States patent No. 762,870, Mar. 16, 1903, described a complicated apparatus for treating ores with oil and other chemicals under super-atmospheric pressure.

JACOB DAVID WOLF, in United States patent No. 787,814, May 22, 1903, duplicated British patent No. 4,793, May 22, 1903.

JACOB DAVID WOLF, in British patent No. 4,793, May 22, 1903, described a method of applying the principles of oil flotation. He used sulpho-chlorinated oil, with violent agitation in a mixer like Fig. 2, and aimed to secure a high degree of mineral extraction with a low grade of concentrate in the first step, and by washing the concentrate with hot water in a suitable vessel

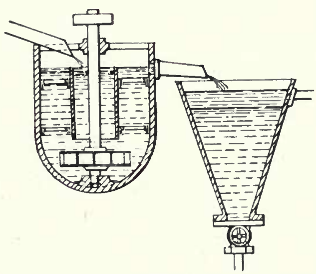


FIG. 2.—Wolf Apparatus.

to increase the grade of concentrate in the second step; as a third step in his process, air or steam was blown into the refuse, which raised to the surface globules of lost oil, with some sulphides adhering thereto, thus increasing the extraction.

COSMO KENDALL, in United States patent No. 771,075, July 21, 1903, described a process of separating graphite from gangue by means of oil.

GOYDER & LAUGHTON, in British patent No. 16,839, July 31, 1903, described a process of ore concentration that employed the idea of adding the ore to an acid solution. They describe an apparatus for trapping the mineral sulphides as they are brought to the surface. They were the first to disclose the principle governing Potter's and Delprat's acid-flotation processes, namely, that the action of the acid on the ore generated gas-bubbles to which the sulphide particles attached themselves and were floated to the surface. One of the difficulties of the acid-flotation process

was that the bubbles broke on reaching the surface, and the mineral particles sank again, that is, the surface tension was not active enough to hold them up. This invention not only seeks to obviate this bad feature of the acid-flotation process, but in a measure takes advantage of it. This machine has horizontal

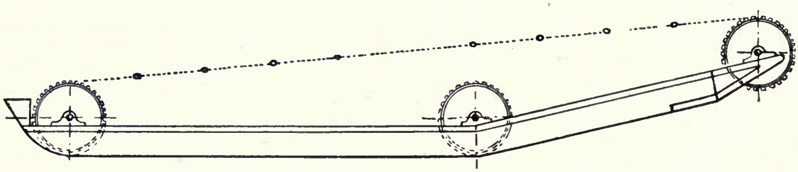


FIG 3.

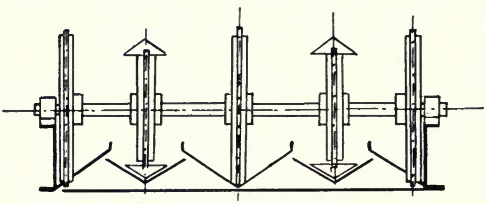


FIG. 4.—Goyder and Laughton Apparatus.

sections decreasing in area upward.

GOYDER & LAUGHTON, in United States patents No. 763,749 and 784,999, Aug. 5, 1903, described an improved form of apparatus and process for the application of the acid-flotation process of Potter, being a duplicate of British patent No. 16,839, July 31, 1903.

CATTERMOLE, SULMAN & PICARD, in British patent No. 17,109, Aug. 6, 1903, described a process of concentration that consisted (1) in mixing the freely flowing pulp with a soap solution and agitating; (2) adding a small portion of acid to liberate the fatty acid from the soap, whereby the sulphides collected in granules, as disclosed previously by Cattermole, and were removed from the pulp by an upcast current of water; and (3) generating a gas in the pulp to remove the granules by flotation. After the concentrate was removed it was treated with an alkali, which dissolved the oil of the granules, converting it into a soluble soap, which was immediately available for use again.

MORITZ F. R. GLOGNER, in United States patent No. 736,381, Aug. 18, 1903, described a process for the recovery of graphite, by means of an oil and froth process.

JACOB DAVID WOLF, in New South Wales patent No. 13,571, Aug. 19, 1903, duplicated his British patent No. 4,793 of May 22, 1903.

VAN METER & BOSS, in United States patent No. 762,774, Aug. 19, 1903, described an apparatus for the application of the oil-buoyancy process.

ALFRED SCHWARZ, in United States patent No. 766,289, Aug. 19, 1903, described a process for separating sulphides from gangue by the use of oil and saline solutions or other liquids differing in specific gravity. His apparatus is different from any previously described, and he gives a theory for his process which it is difficult to accept.

ARTHUR EDWARD CATTERMOLE, in British patent No. 18,589, Aug. 28, 1903, secured a revision and amplification of his previous patents, and described the formation of granules. He describes an improved form of apparatus. This process failed of practical application.

HOMER L. ORR, in United States patent No. 758, 464, Sept. 1, 1903, described an apparatus for separating metallic particles in an ore by means of oil and other chemicals.

GUILLAUME DANIEL DELPRAT, in British patent No. 19,783, Sept. 14, 1903, described a flotation process wherein the bisulphate of an alkali metal is used.

SULMAN & PICARD, in British patent No. 20,419, Sept. 22, 1903, described a process of oil-concentration in which they introduced bubbles of air or other gas, and also oil in the form of a spray, into the freely flowing acidulated pulp. This invention follows some of their previous patents in its main lines, but is novel in the methods of introducing the oil and air into the slightly oiled pulp.

SULMAN & PICARD, in New South Wales patent No. 13,632, Sept. 24, 1903, described a process consisting in the recovery of metallic particles in an ore by floating them to the surface with bubbles and films of air after oiling them with a small amount of oil in an acid circuit.

ARTHUR EDWARD CATTERMOLE, in United States patent No. 763,260, Sept. 28, 1903, duplicated British patent No. 26,295, Nov. 28, 1902.

ARTHUR EDWARD CATTERMOLE, in United States patent No. 777,273, Sept. 28, 1903, duplicated British patent No. 18,589, Aug. 28, 1903.

ARTHUR EDWARD CATTERMOLE, in United States patent No. 763,259, Sept. 29, 1903, duplicated British patent No. 26,296, Nov. 2, 1902.

SULMAN & PICARD, in United States patent No. 793,808, Oct. 5, 1903, duplicated British patent No. 20,419, Sept. 22, 1903.

ALICE H. SCHWARZ, in United States patent No. 771,277, Nov. 6, 1903, described a process of ore concentration in which she made use of an oil or grease that is solid at ordinary temperatures.

ISRAEL F. GOOD, in United States patent No. 745,960, Dec. 1, 1903, described an oil-flotation method of recovering graphite from rock.

GUILLAUME DANIEL DELPRAT, in British patent No. 27,132, Dec. 11, 1903, described the use of a solution of common salt and sulphuric acid to be used in the acid-flotation processes previously disclosed by him.

ALEXANDER STANLEY ELMORE, in United States patent No. 865,334, Dec. 11, 1903, duplicated British patent No. 184, Jan. 3, 1903.

EDMUND B. KIRBY, in United States patent No. 809,959, Dec. 14, 1903, described a process of oil-and-gas flotation, in which air was blown into the previously agitated oiled pulp.

CATTERMOLE, SULMAN, & PICARD, in United States patent No. 788,247, Mar. 29, 1904, duplicated British patent No. 17,019, August 6, 1903, in part.

CATTERMOLE, SULMAN, & PICARD, in United States patent No. 777,274, Mar. 29, 1904, duplicated in part British patent No. 17,109.

JAMES D. DARLING, in United States patent No. 763,859, April 28, 1904, described a method of separating carbon from impurities by means of oil.

SULMAN & PICARD, in British patent No. 13,481, June 14, 1904, described a method of slime-deposition by means of soap, which produces coagulation. This is of limited interest to this discussion.

FRANCIS EDWARD ELMORE, in British patent No. 13,578, June 15, 1904, described a process of flotation wherein he made use of the electrolysis of water to generate gas in a freely flowing pulp. This patent is chiefly of interest in that it marks the departure of this inventor from his old line of oil-buoyancy flotation, emphasized in his former patents, and he thenceforth turns his attention to gas-and-oil flotation.

JACOB DAVID WOLF, in British patent No. 17,407, Aug. 10,

1904, described an apparatus similar to that of Haultain & Stovel.

Francis Edward Elmore, in British patent No. 17,816, Aug. 16, 1904, described a process to be performed in a vacuum or a partial vacuum. He says he uses a small quantity of oil, and also says that " under a vacuum or partial vacuum, air or gases dissolved in the milling water are liberated. These liberated gases may be augmented by the generation of gases in the pulp, or by introduction from an external source." The apparatus is an admirable invention, and the patent discloses a new principle, namely, the use of the vacuum in connection with the flotation.

Auguste Joseph Francois De Bavay, in British patent No. 18,660, Aug. 29, 1904, described a flotation process in which a thin film of freely flowing pulp was brought on to the surface of a vessel of water, where advantage was taken of the surface tension of the liquid, and the sulphide floated. He further points out that if the surface of the sulphide particles is coated with a film of carbonate from weathering, this is detrimental to the process, and should be removed by (1) soaking the ore in a weak solution of carbonate of ammonia, or (2) passing carbonic gas through the pulverised wet ore, or (3) by friction.

James Hyndes Gillies, in United States patent No. 778,747, Sept. 7, 1904, duplicated British patent No. 20,159, Sept. 19, 1904

James Hyndes Gillies, in United States patent No. 780,281, Sept. 8, 1904, duplicated British patent No. 20,160, Sept. 19, 1904.

James Hyndes Gillies, in British patent No. 20,159 and No. 20,160, Sept. 19, 1904, described an apparatus to be used in conducting the Potter and Delprat processes.

Sulman & Picard, in Commonwealth patent No. 1,909, Oct. 27, 1904, duplicated their N.S.W. patent, No. 13,632.

Alfred Schwarz, in British patent No. 23,906, Nov. 4, 1904, described a process of concentration wherein he added to a dry or slightly wet pulp a portion of fat, oil, or resinous substance, which was solid at ordinary temperature. After several complicated manipulations, the oil and mineral were separated from the gangue by flotation. This is a duplicate of United States patent No. 771,277, Oct. 7, 1904, by Alice H. Schwarz.

Arthur Penrhyn Stanley Macquisten, in British patents No. 25,204 and No. 25,204 A, Nov. 19, 1904, described a process and apparatus therefor, making use of the surface tension of

liquids for separating minerals, whereby some floated and others sank. His apparatus is new and important, but works on the old and well known principle of surface tension.

Auguste Joseph Francois De Bavay, in British patent No. 25,858, Nov. 28, 1904, described an apparatus for mineral separation by the process described in his patent of Aug. 29, 1904, previously mentioned.

Auguste Joseph Francois De Bavay, in United States patent No. 864,597, Dec. 19, 1904, duplicated British patent No. 18,660, Aug. 29, 1904.

Auguste Joseph Francois De Bavay, in United States patent No. 912,783, Dec. 19, 1904, described an apparatus for performing processes at pressures above normal.

Sulman, Picard, & Ballot, in British patent No. 29,374, Dec. 31, 1904, described a process and apparatus therefor wherein they made use of the idea of oil-and-gas flotation combined with surface tension. A mineral particle coated with a film of oil not only adheres to a small bubble of air or other gas introduced into the pulp and floats with the bubble, but all oiled particles that are exposed to the air above the surface of the pulp take unto themselves films of air of much larger dimensions than if un-oiled, and so float more readily than un-oiled particles.

Francis Edward Elmore, in British patent No. 29,282, Dec. 31, 1904, described an apparatus to perform the operation described in his vacuum-process patent.

Sulman & Picard, in British patent No. 1,821, Jan. 30, 1905, described a process that depends on the surface tension of the liquid.

Sulman, Picard, & Ballot, in United States patent No. 879,985, Feb. 2, 1905, duplicated British patent No. 29,374, Dec. 31, 1904.

Walter Murray Sanders, in United States patent No. 805,382, Feb. 7, 1905, described a method of gas-flotation in which he used alkaline solutions to generate bubbles of hydrogen gas on the minerals.

Sulman, Picard, & Ballot, in British patent No. 5,260, Mar. 13, 1905, described a process of flotation in which they revert to surface tension as applied to dry ores. In the simplest method described by them they sprinkle the dry ore on the surface of the liquid in a spitzkasten. The sulphides being more difficult to wet, or rather, adhering more strongly to their air-films than the gangue, floated, and the gangue sank.

Alexander Stanley Elmore, in British patent No. 5,953, Mar. 21, 1905, described a method of using calcium chloride and other chlorides in flotation-concentration.

Sulman, Picard, & Ballot, in British patent No. 7,803, April 12, 1905, described a process of flotation in which they added extremely small amounts of oil, less than 0.1%, to a freely flowing pulp, and gave it violent agitation for from 1 to 10 minutes.

Cyril Douglas McCourt, in British patent No. 10,475, May 18, 1905, described a process for concentrating graphite and other non-metallic substances by means of oil-flotation. No new principle is disclosed herein, but previously patented processes are put to a new use.

Sulman, Picard, & Ballot, in United States patent No. 835,120, May 29, 1905, duplicated British patent No. 7,803, April 12, 1905.

Sulman, Picard, & Ballot, in United States patent No. 835,479, May 29, 1905, duplicated British patent No. 26,712, Dec. 21, 1905.

Henry Livingstone Sulman, in Commonwealth patent No. 4,667, June 6, 1905, duplicated his invention in British patent No. 19,709, Sept. 25, 1905.

Arthur Penrhyn Stanley Macquisten, in United States patent No. 865,194, July 3, 1905, duplicated British patent No. 25,204, Nov. 19, 1904.

Francis Edward Elmore, in United States patent No. 826,411, July 10, 1905, duplicated his process in British patent No. 17,816, Aug. 16, 1904.

Alfred Schwarz, in United States patent No. 825,080, July 12, 1905, described an improved form of apparatus for use in his processes previously described.

Alfred Schwarz, in United States patent No. 842,255, July 19, 1905, duplicated British patent No. 23,906, Nov. 4, 1904.

Arthur Penrhyn Stanley Macquisten, in British patent No. 15,119, July 22, 1905, described an improvement to his surface-tension process, in which he made use of oil and various salts and acids.

Henry Livingstone Sulman, in British patent No. 19,709, Sept. 29, 1905, described an improvement upon the previous oil-and-gas process; this consisted in bringing the contents of the agitating-vessel to a boiling temperature.

JACOB DAVID WOLF, in British patent No. 20,322, Oct. 7, 1905, described an improvement to his greased-belt apparatus.

HENRY LIVINGSTONE SULMAN, in United States patent No. 835,143, Oct. 20, 1905, duplicated British patent No. 19,709, Sept. 29, 1905.

SULMAN, PICARD, & BALLOT, in British patent No. 26,711, Dec. 21, 1905, described a process for separating heavy sulphides from each other. They begin with the known fact that in a pulp containing mixed sulphides in a sunken condition, if the sulphides are raised above the surface and allowed to drain, the sulphides take unto themselves films of air, and upon again seeking to immerse the drained pulp, the sulphides float; and they discovered also that the time required for drainage and taking on of air-films varied in the different sulphides. By taking advantage of these drainage periods of different lengths they could effect a separation of the sulphides from each other. This is a novel conception, but the practical application of it has been a failure.

SULMAN, PICARD, & BALLOT, in British patent No. 26,712, Dec. 21, 1905, described a method of applying oil-and-gas flotation. This consisted in subjecting a freely flowing oiled pulp to pressure for the purpose of dissolving air or other gas therein, and when the pressure on the pulp was removed the air immediately escaped from solution and collected the oiled minerals and floated them; also the introduction of highly aerated water with the pulp for the same purpose. They make use herein of facts well known in physics under the name of Henry and Dalton's law, namely, the quantity of gas dissolved in water is in direct proportion to the pressure.

SULMAN, PICARD, & BALLOT, in Commonwealth patent No. 5,150, Jan. 31, 1906, duplicated British patent No. 26,712, 1905.

SULMAN, PICARD, & BALLOT, in Commonwealth patent No. 5,334, Feb. 26, 1906, duplicated British patent No. 26,711, 1905.

ARTHUR PENRHYN STANLEY MACQUISTEN, in United States patent No. 865,195, Mar. 17, 1906, duplicated British patent No. 25,204A, Nov. 19, 1904.

JAMES FRANCIS LATIMER, in United States patent No. 851,600, Mar. 27, 1906, described flotation processes as applied to graphite concentration.

SULMAN & SULMAN, in British patent No. 9,981, April 28, 1906, described the adaptation of the buddle and rubber strakes to flotation processes, whereby the particles are exposed to the air advantageously.

Auguste Joseph Francois De Bavay, in Commonwealth patent No. 6,239, June 21, 1906, described a flotation process where a fluoride or a carbonate is added to the acid pulp.

George Albert Chapman, in British patent No. 17,328, Aug. 1, 1906, described an improvement to Sulman's previous patents. This is a method of limiting the amount of acid used in flotation. While it is advantageous to have some acid in the pulp to increase the selective action of the oil, it is not necessary to maintain the acidity of the whole mass for more than a short time; the operation can be carried on in a neutral circuit if the acid is added before the oil. This is a working detail of considerable importance.

Henry Livingstone Sulman, in British patent No. 19,944, Sept. 7, 1906, described a process in which the separation of minerals was brought about by the repeated exposure of the particles to the air, and by warming the liquid in which the operation was performed.

Walter Murray Sanders, in United States patent No. 988,737, Oct. 27, 1906, patented a non-acid process of flotation-concentration.

Dudley Hiram Norris, in United States patent No. 864,856, Nov. 19, 1906, described a method of effecting a separation of minerals by flotation by adding to a freely flowing pulp a portion of water in which air was dissolved at high pressure. His apparatus is new.

Walter Murray Sanders, in United States patent No. 911,077, Mar. 27, 1907, described an apparatus for performing flotation processes.

Hoover & Sulman, in British patent No. 13,268, June 7, 1907, described an apparatus for performing the high-pressure operation previously described by Sulman, Picard, & Ballot.

Dudley Hiram Norris, in amended British patent No. 14,806, June 27, 1907, duplicated his United States patent No. 864,856, 1906, with modifications.

Marcus Ruthenburg, in British patent No. 28,191, Dec. 21, 1907, described a method of separating mixed sulphides by using a light oil instead of water, in ordinary table or vanner concentration.

Lockwood & Samuel, in British patent No. 12,962, June 17, 1908, patented a process for making sulphide particles more magnetic by utilizing the selective action of oil.

Frank Burnett Dick, in British patent No. 16,667, Aug. 7, 1908, described a process for treating copper ores by an oil-and-gas flotation process, where the ore is given a preliminary preparation by a reducing roast.

Lockwood & Samuel, in British patent No. 26,264, Dec. 4, 1908, described a method of increasing the selective action of oil by treating it with various salts.

Arthur Howard Higgins, in British patent No. 26,852, Dec. 10, 1908, described a flotation process in which the frothing agents are aromatic hydroxides such as phenol.

Sulman, Picard, & Ballot, in British patent No. 28,173, Dec. 24, 1908, described a method of securing flotation by the use of soluble frothing agents of the alcohol series.

Henry Azor Wentworth, in United States patent No. 938,732, Jan. 2, 1909, described a process of separating sulphides from each other where the sulphides were submitted to a slight roast for the purpose of rendering one or more of the sulphides non-floatable.

Lockwood & Samuel, in British patent No. 16,229, Jan. 7, 1909, described a process wherein magnetic or magnetizable substances are added to an ore-pulp, the whole then treated with an oil to cause the sulphides and the magnetic particles to adhere together, and then removing them from the pulp in a magnetic machine.

Lockwood & Samuel, in United States patent No. 933,717, Jan. 11, 1909, duplicate in part British patent No. 12,962, June 17, 1908,

Edward James Horwood, in Commonwealth patent No. 12,763, Jan. 13, 1909, described a process for separating zinc sulphide from lead sulphide by flotation, after first giving the concentrate a slight roast.

Edward James Horwood, in amended British patent No. 1,789, Jan, 25, 1909, duplicated his Commonwealth patent No. 12,763, Jan. 13, 1909.

Greenway, Sulman, and Higgins, in amended British patent No. 2,359, Feb. 1, 1909, described a process of flotation-concentration accelerated by the use of soluble frothing agents.

Theodore Jesse Hoover, in British patent No. 4,911, Feb. 27, 1909, described an apparatus for applying the frothing process. This is probably the most important mechanical development in the whole series, and together with its later improvements crystallizes the commercial application of the flotation method.

Greenway, Sulman, & Higgins, in United States patent No. 962,678, April 30, 1909, duplicated British patent No. 2,359, Feb. 1, 1909.

Frank Wynne, in British patent No. 12,266, May 25, 1909, described an oil-belt apparatus.

Jacob David Wolf, in British patent No. 15,469, July 2, 1909, described an improvement to his previous inventions.

Sulman & Picard, in British patent No. 26,019, Nov. 10, 1909, described a flotation treatment for oxidized ores.

Alfred Arthur Lockwood, in United States patent, No. 956,773, Nov. 15, 1909, duplicated British patent No. 26,264, Dec. 4, 1908.

Sulman, Higgins, & Ballot, in British patent No. 28,933, Dec. 10, 1909, described a flotation process where turpentine is the agent.

Frank Burnett Dick, in British patent No. 2,500, Feb. 1, 1910, described an improvement to his invention for the treatment of copper ores described in his British patent No. 16,667 of 1908.

Henry Azor Wentworth, in United States patent No. 980,035, March 11, 1910, described a process of differential separation of mixed sulphides.

Theodore Jesse Hoover, in British patent No. 6,896, Mar. 18, 1910, described a form of apparatus for flotation processes, being an improvement on British patent 4,911 of 1909.

Sulman & Picard, in British patent No. 8,650, April 9, 1910, described a process of preparing ores for flotation treatment, which consists in submitting them to a reducing roast.

Theodore Jesse Hoover, in British patent No. 10,929, May 3, 1910, described a form of apparatus for flotation processes ; a further improvement on British patent 4,911 of 1909.

Alfred Arthur Lockwood, in British patent No. 13,009, May 28, 1910, described a new magnetic flotation method.

Greenway, Sulman, & Higgins, in United States patent, No. 962,678, June 28, 1910, duplicated British patent No. 2,359, Feb. 1, 1909.

Theodore Jesse Hoover, in United States patent No. 979,857, July 14, 1910, duplicated British patent No. 6,896, Mar. 18, 1910.

James M. Hyde, in United States patent No. 1,022,085, April 2, 1912, described an apparatus and flotation process where the acid required is added at some time and distance

prior to the act of flotation; the patent contains the first description of an ingenious method of making high grade concentrates and high recovery simultaneously.

CHAPTER III.

LITIGATION.

In the previous chapter 140 patents were summarized, but out of them it would not be possible to cull 140 new ideas. Besides the dearth of ideas, the question of priority and the fact of diffuse ownership were bound to give rise to a complicated mass of litigation.

The patent law has been one of the greatest accelerating factors in our modern civilization, because it has offered an adequate potential reward to individual effort. When inventions were few and widely differentiated, Governments were able to give adequate protection to the inventive class, there being in the nature of things little interference or clash of interests. However, after a hundred years of highly accelerated development, we have arrived at a point where it is obvious that either the patent idea or its method of operation has completely broken down. The historical situation is changed for another reason, namely, a patentee has to protect himself not only in his own country, but all over the world, and to conduct independent law-suits in each country.

Men nowadays work conscientiously and expend their energy in the development of ideas, only to learn later that these have already been the subject of patents, and that no new patent will be granted. The man who does this can attribute a part of his misfortune to his own fault, for the law presumes he has knowledge of precedent inventions. The individual who has received letters patent on an idea, however, and later finds that this brings him no reward when the matter is adjudicated in the courts, certainly deserves sympathy. He is in an entirely different position from the first man; the Government has passed his invention as patentable, and if later the courts deprive him of the benefits definitely promised, someone has blundered. Every legal case in which the patents of one litigant are declared invalid is an indictment of the most serious nature against the system. Leaving out of account the victims of patent 'pirates'—unfortunately a

large class—there are numerous well-intentioned people who have been deceived as to the value of the contract and covenant issued by the Government purporting to guarantee to them, their heirs and assigns, certain definite benefits and profits. The industrial world is alive to this breakdown, and a discussion of remedies has occupied the attention of serious reformers. The captains of industry have met this *impasse* in a measure by suppressed knowledge and secrecy in the arts. No better exposition of the iniquity of such secrecy can be made than that of James Douglas in the 'Transactions of the American Institute of Mining Engineers,' Vol. XXXIX., 1907. This paper is so able, and deals with a subject of such wide economic interest, that it deserves much wider circulation than it has had. The suppression of knowledge and secrecy in the arts is grossly contrary to the public weal, and deteriorating to the individual. It threatens to stifle industrial development, because the incentive of the potential reward, to a large extent, is withdrawn. Sooner or later Governments must undertake to make their guarantees good. They must make the letters patent a contract as inviolable as the simple language on the face of it now would lead a sensible man to believe. The amount of money spent in patent litigation (including the expenses of the courts), and in the patent office of either the United States or Great Britain, is a heavy tax on industry, and it yields no economic result. The men who are most competent to judge in these cases are not called until the matter is before the courts, technical and scientific men of ability and training generally being conspicuous by their absence. The patent commissioner, or chief, is generally a politician, whose chief ambition is to draw his salary with a minimum of effort. Examination by the patent office should be thoroughly scientific. As no expert examiner has perfect knowledge, the specification, as determined by the official examiner, before final sealing should be published in the recognized technical press covering the particular subject of the patent, announcing that unless valid objections are submitted within six months the patent shall hold good from the date of publication, and be a perfect protection against any possibility of the patent ever being the subject of a law-suit. This would fix 'knowledge at the time,' and prevent professional unearthing of old and abandoned ideas.

DECIDED CASES.

All the legal cases that in any way bear on the validity or

ownership of this complex and tangled series of patents are here summarized :

ELMORE *v.* VAN METER.—The Elmore company, in 1902, opposed the granting of patents to Van Meter in Peru, but, after a hearing, the patents were granted. A compromise was subsequently effected between these two interests, by which the Van Meter patents were absorbed by Elmore.

SULMAN & PICARD *v.* WOLF.—Decision given in May, 1905. This was an action brought in the Chancery division of the English courts, before Mr. Justice Buckley, by Sulman & Picard, metallurgical chemists, against Wolf, inventor of a flotation process, for fees that Sulman & Picard claimed were due for work done on Wolf's process. Wolf counter-claimed that Sulman & Picard had violated their contract with him in that, being employed by him to investigate his process, they used the information obtained thereby, and took out patents in respect to certain discoveries that they made for him, and which they ought to have handed over to him. The counter-claim stated that this claim was unwarranted for the reason that Sulman & Picard had notified Wolf before he employed them that they were interested professionally and commercially in another similar oil process belonging to Minerals Separation, Ltd. They informed him that, in view of their opinion that this new process would prove superior to Wolf's, they did not feel justified in accepting fees from him, and suggested he retain the services of someone else to conduct his trials. Nevertheless, Wolf entered into an agreement whereby Sulman & Picard were, among other things, to give him the benefit of all discoveries made in the course of their investigation of his process. The learned judge held that they had fulfilled every undertaking of the contract, and in the course of his judgment construed the meaning of various oil patents submitted to him as follows :

The Elmore process was for treating crushed ore by mixing with water and oil, so that the gangue shall become loaded with water and shall sink, and the sulphides shall become engaged by the oil, and shall float as by little rafts of oil. The process in which Wolf was interested was a process of the Elmore type, and was the subject of a patent by Scammell. Scammell's improvement on the Elmore process consisted in increasing the viscosity and cohesion by treating the oil with sulphur chloride. As a result of the investigation of this Elmore–Scammell process by Sulman & Picard, Wolf ultimately took out a patent for a process

that was of the Elmore-Scammell type, with this improvement: that after the oil had rafted off the sulphides, air was blown through the tailing to recover the oil that had been lost in the tailing. The other process that Sulman & Picard were investigating was different altogether. In this process, belonging to the Minerals Separation, Ltd., a very small quantity of oil was used, the original object being not to float the sulphides, but to collect the sulphides together in the form of granules and make them sink, adding just enough oil to act as a cement for the granules. Later this process was improved by the Minerals Separation, Ltd., in such a way that by introducing air into the pulp the granules could be made to float by the attached air-bubbles. This was not flotation by oil, but flotation by air. The only point of resemblance between the Elmore-Scammell-Wolf process and the process of Minerals Separation, Ltd., was that they both used a jet; but the object of the jet in Wolf's case was to recover lost oil, while in the other case it was used to make the sulphides float, and so recover them. The learned judge, therefore, held that Sulman & Picard had discharged every obligation faithfully, and that Wolf must pay the fees agreed upon.

De Bavay *v.* Macquisten. Decision delivered in Jan., 1907. Macquisten applied for a patent in Australia for his process, which involved the use of the surface tension of water applied in a slowly revolving tube. De Bavay opposed the granting of this patent, but, after hearing the evidence of both parties, the Commissioner decided that Macquisten was entitled to his patent.

Potter *v.* The Broken Hill Proprietary Company. Decision delivered in February, 1907. This was an action brought in Australia by Charles V. Potter, inventor of an acid-flotation process, against the Proprietary company for infringement by the use of the Delprat process. Delprat pleaded that Potter's patent was invalid because:

(1) It will not do as much as it professes to do with any sulphide ores.

(2) That with some sulphide ores it will not work at all.

(3) That with many sulphide ores it will not work with any result that could be useful.

(4) That it will not work with the class of ore mentioned in the specification.

(5) That it will not work with slime.

(6) That although the patentee says that any acid may be

used, some acids will not be operative, and an acid that will be operative on one ore will not be operative on another.

Much detailed evidence was presented to the Court on these points, and Mr Justice à Beckett decided that Potter's patent was invalid for want of utility, for the following reasons :

" (*a*) That with many ores no such separation can be " effected, although partial separation can be effected.

" (*b*) That in many instances in which high percentages of " separation have been obtained in flotation of sulphides a large " percentage of gangue has been floated with the sulphides.

" (*c*) That some ores are not amenable to the process under " any condition.

" (*d*) That in cases in which only part of the sulphides are " floated no reason can be assigned for the other part of the sul- " phides failing to float, and no repetition or variation of the " process will make this part float.

" (*e*) That no assay or examination of a particular ore will " enable an operator to discover whether with that ore the process " will be successful wholly or partially, or will fail altogether."

On the other hand, the court held that the Delprat process would have been an infringement if Potter's patent had not been invalid by reason of having been badly drawn up. There was no question but that Potter had a novel idea.

This unsatisfactory decision was at once appealed to the High Court of Australia, but before the High Court was called upon to revise the findings of Mr. Justice à Beckett, a compromise was effected as follows :—

(1) Potter granted to the Proprietary company the right to use free his process in Australia.

(2) The Proprietary company assigned to Potter all the Delprat patents in Australia.

(3) The Proprietary company paid Potter £10,000 in cash.

(4) Each party paid its own costs.

In view of the compromise it would seem that the defendants had little confidence in Mr. Justice à Beckett's decision.

Ore Concentration Company, Ltd., *v.* Webster and Others. Decision rendered in October, 1908. This was a suit brought in the King's Bench division of the English courts before Mr. Justice Darling by the owners of the Elmore process against Webster and others for damages for non-fulfilment of contract. The Elmore company and Webster *et al.* had entered into a

contract some years before, wherein Webster *et al.* were given an option on the rights of the old Elmore process for Australia at a fixed price, and were to be allowed to inspect and investigate the Elmore process previous to exercising the option. Among other clauses in the option was one providing that any patents for improvements in oil-concentration acquired in any way by Webster and associates should become the property of the Elmore company, and be treated for the purpose of the option as if they were the original patents. After investigating the Elmore process for some time, Webster and associates come to the conclusion it was not what they wanted and they allowed their option to expire, and so waived all their rights and lost the payments they had already made. Some time later, A. E. Cattermole brought on the market his oil process, and after offering to sell the patent rights to the Elmore company and others unsuccessfully, he offered them to Webster and associates. After due consideration, Webster and associates formed a syndicate, into which they took a number of other people, and this syndicate purchased the Cattermole, Froment, Sulman & Picard, and other oil-process patents. Webster and Ballot, two of the holders of the old option on the Elmore process for Australia, were directors of the new syndicate, which was called Minerals Separation, Ltd. The Elmore company then brought a suit against Webster, Ballot, and Hay, to enforce the clause in the contract above mentioned.

After hearing evidence on the negotiations leading up to the option, Mr. Justice Darling delivered judgment to the effect that the particular clause had been introduced into the contract without authority after it had been signed, sealed, and delivered by both parties, and that therefore the Elmore company was not entitled to any redress.

The Elmore company appealed from Mr. Justice Darling's decision to the Court of Appeal, which court, after hearing the arguments of counsel, ordered that the judgment of Mr. Justice Darling be set aside and a new trial held.

The new trial was held in the Chancery division of the English courts before Mr. Justice Parker. In this trial the Elmore company introduced evidence to show that the Minerals Separation processes were oil-flotation processes, similar to the Elmore processes, and that they belonged rightfully to the Elmore company under the terms of the clause of the option above-mentioned. Webster and associates introduced evidence to show that they

had never owned these patents; that they were never in their possession but had been bought by a trustee of the syndicate, and had passed directly from the inventors through a trustee to the Minerals Separation Syndicate. When the proceedings reached this stage, the learned counsel for the plaintiffs asked the Court for a moment to confer with the learned counsel for the defendants. Thereupon it was mutually agreed between the plaintiffs, the defendants, and the Court, that the proceedings be stayed on the following terms:

That both parties to the action pay their own cost.

That the option agreement be treated as if the clause referred to were struck out altogether.

The result of this piece of litigation leaves the impression that it was unnecessary and wasteful.

ELMORE *v.* MINERALS SEPARATION, LTD. Decision delivered May, 1909. The Minerals Separation, Ltd., through Sulman, Picard, and Ballot, applied for a patent in Germany. This was opposed by Elmore, but the patent was granted. The Elmore company appealed from the decision of the Patent Office to a higher court, which reversed the decision of the Patent Office.

MINERALS SEPARATION, LTD., *v.* NORRIS. Decision rendered May, 1909. Dudley Norris applied for a patent in England for a method of introducing air into an oiled pulp. This was opposed by the Minerals Separation, Ltd., and after hearing evidence the law officer held that practically all but one of Norris's claims were anticipated by the earlier patents of Hoover & Sulman.

MINERALS SEPARATION, LTD., *v.* POTTER. Decision rendered July, 1909. After the Potter company had compromised with the Delprat interests they applied for amendments in Australia with a view to overcoming the invalidity in their patents as indicated by Mr. Justice à Beckett. These amendments were opposed by the Minerals Separation, Ltd. The case was heard before the Commissioner of Patents, and some of the amendments were granted and others rejected. The Minerals Separation, Ltd., appealed from the decision of the Commissioner to the High Court of Australia, and this court decided in favour of Potter, and the amendment was granted. In December, 1909, Minerals Separation, Ltd., applied to the Privy Council in London for permission to appeal from the High Court of Australia, but the application was denied on the grounds that the case could only come before them on a question of infringement.

British Ore Concentration Syndicate, Ltd., and Alexander Stanley Elmore, *v.* The Minerals Separation, Ltd. Decision rendered in November, 1909. This was a suit brought by the Elmore interests, owners of an oil-concentration process, asking for " an injunction restraining the defendants from using " ores or mineral substances treated by any one of the processes " described and claimed respectively in the specifications of " letters patent No. 21,948 of 1898, and 6,519 of 1901, of which " the plaintiffs are the registered legal owners." The trial case was heard in July, 1908, by Mr. Justice Neville, of the High Court of Chancery, who, after an inquiry lasting seven days, pronounced judgment to the effect that the Minerals Separation, Ltd., owners of the Minerals Separation process, were not infringing. In his judgment Mr. Justice Neville made the following points :

(1) The selective action of oil for sulphides was known before Elmore obtained his patents, and was disclosed in prior expired patents.

(2) Elmore's patent was for a process wherein a large quantity of oil was used, sufficient to carry all the sulphides to the surface by the buoyancy of the oil.

(3) The Minerals Separation process used only an infinitesimal amount of oil for the purpose of attaching air-bubbles to the sulphides, and so causing them to float by the buoyancy of the air-bubbles.

(4) The use of acid in oil processes was known before Elmore obtained his patents and was disclosed in prior expired patents.

Mr. Justice Neville then summed up in these words :

" I think, therefore, in that case, whether you take it that " the patent is confined to the 1898 patent, or whether you take " it generally, the defendants have not infringed, or they have " infringed a patent which has no validity, and consequently no " relief can be granted against them."

The plaintiffs (the Elmore company) appealed from this decision and the appeal was heard in the Court of Appeal before the Master of the Rolls, Lord Justice Fletcher Moulton, and Lord Justice Farwell, in November, 1908. Judgment was rendered on December 2, reversing the decision of the lower court and finding that Minerals Separation, Ltd., were not infringing the 1898 patent, but were infringing the 1901 patent. An injunction was granted as applied for. Lord Justice Fletcher Moulton's idea of the patents in question was as follows :—

(1) That the first Elmore patent was not anticipated by previous expired patents.

(2) That if Minerals Separation used a thin oil they would not infringe Elmore.

(3) That the second Elmore patent was not anticipated by previous expired patents.

(4) That the Minerals Separation infringed the second patent by using acid.

The Court of Appeal thereupon reversed Mr. Justice Neville's decision and granted the injunction against Minerals Separation, Ltd.

The Minerals Separation, Ltd., appealed from this decision to the House of Lords—the court of last resort—and on November 16, 1909, the Lord Chancellor and Lords Halsbury, Ashbourne, Atkinson, and Shaw, reversed the judgment of the Court of Appeal and upheld the judgment of the trial court as follows :

The Lord Chancellor held that the Elmore patents were drawn up with great subtlety in order that the claims might be expanded or contracted as occasion might require in the interests of the patentee ; that the only definite claim in the patent was for acidulation, and that this was anticipated in the expired Everson patent ; therefore the Elmore patents could not be sustained.

Lord Halsbury held that the Elmore and the Minerals Separation processes were essentially different, in that the one was based on the selective action of oil, and the other on surface tension ; that Elmore had no valid claim to acidulation, because it was known and had been previously described ; that the Elmore patent should not be upheld, if for no other reason than because of its ambiguity.

Lord Atkinson held that the Elmore process was the addition of a small quantity of acid and a relatively large quantity of oil to a mixture of ore and water, where the oil, in accordance with some obscure law of affinity, seized upon the minute particles of ore in preference to the earthy particles, and, by the buoyancy of oil, floated them to the surface ; that the Minerals Separation did not infringe this process because their process was one where they made use of the known selective action of oil, yet the oil was used in relatively small quantities, and the metallic particles were only coated with a thin film of it, and the lifting force was found, not in the buoyancy of the oil, but in the natural buoyancy of the air-bubbles, which, introduced into the mass by violent agitation,

envelop or become attached to the oiled mineral particles and raise them to the surface.

Lord Shaw held that the two processes were essentially different, so much so, that apart from the question of the prior state of knowledge of the art, there was no infringement.

Lord Ashbourne concurred with the decision of their lordships, thus making the judgment of the Court unanimous.

UNDECIDED CASES.

ELMORE *v.* THE SULPHIDE CORPORATION, LTD. The Elmore company filed a writ in Australia alleging that the Sulphide Corporation is infringing the Elmore patents by the use of the Minerals Separation process. The case came to trial in New South Wales, and was decided in favour of the Sulphide Corporation, but an appeal to the Privy Council is now pending.

POTTER *v.* THE SULPHIDE CORPORATION, LTD. The Potter Sulphide Process Co. filed a writ in Australia alleging that the Sulphide Corporation is infringing the Potter patents by the use of the Minerals Separation process. This suit has now been withdrawn as a result of the amalgamation of the interests involved.

MINERALS SEPARATION, LTD., *v.* DE BAVAY. The Minerals Separation, Ltd., filed a writ in Australia alleging that the Amalgamated Zinc, Ltd., is infringing the Minerals Separation patents by the use of the De Bavay process. This suit also has been withdrawn as a result of the amalgamation of the interests involved.

MINERALS SEPARATION, LTD., *v.* HYDE. The Minerals Separation has brought a suit against James M. Hyde alleging infringement on the Butte and Superior mine, in Montana, U.S.A.

All this mass of litigation is inconclusive. No one of these suits would involve a decision on all the patents. In fact, if all the law-suits already started were brought to a final decision it is doubtful whether the public would know whether they could use the processes of the successful litigants without fear of further litigation. If the whole situation could be placed before a competent court to decide on merit it would be far preferable to the engineer, but it might be less acceptable to the legal profession, for obvious reasons.

CHAPTER IV.

THEORIES.

An entirely unnecessary veil of mystery has been suffered to obscure the theoretical side of flotation processes. The forces involved, it is true, are not of such common cognizance as are those in the older methods of gravity concentration, but they are no more wonderful or mysterious in the one case than in the other. The forces utilized are finite in the range of their manifestations, but we have to appeal to molecular considerations for a complete exposition. The imagination of professional engineers is so well trained in these days that they should have no difficulty in grasping the significance of most of the observed facts, and there is, therefore, no reason why anybody engaged in metallurgical pursuits should not become as familiar with these methods of ore treatment as with any other.

A few analogies may be instanced in order to inspire confidence and allay the well established fear of the mysterious. For example, the amalgamation treatment of gold ores, wherein crushed ore, water, and quicksilver are mixed in proper proportions and in suitable devices, is so well known, and metallurgists have become so familiar with it, that the wonderful and obscure molecular reactions between the gold and the quicksilver are never given any thought. Again, the chemical reactions characterizing the cyanide treatment of gold ores, though we are in a measure able to quantify them by a familiar symbolism, require an undoubted exercise of the imagination by means of a written or mental picture of $KCy + Au = KAuCy$. So in the case of flotation-concentration processes the physical laws are for the most part plain ; and where obscure, the obscurity is not a matter that need obstruct practical application. It is not my purpose to enter into a mathematical or physical discussion of the laws regulating these forces. James Clerk Maxwell, in his classical article on 'Capillary Action,' in the ninth edition of the *Encyclopedia Britannica*, has laid the foundation for a mathematic demonstration of all the phenomena involved ; moreover

H. Livingstone Sulman and Hugh F. K. Picard have in preparation a full dissertation on the observed facts of surface tension and oleaginous and gas-film adhesion, with special reference to their bearing upon concentration by flotation. Sulman & Picard's essay is a document of the highest scientific quality, and we have had a pleasant foretaste of its merit in Sulman's recent announcement of the hysteresis range of the contact angle.

My purpose is to give a description in plain and simple language of what takes place when a particle of mineral floats at the surface of a liquid, leaving the mathematical and molecular aspects of the subject to be discussed at some future time.

Unfortunately, the nomenclature hitherto adopted in discussing the laws and principles governing flotation processes has not been such that it carried any explanation with it, but it is the better part of wisdom not to attempt to introduce new terms. I must confess to an inexplicable dislike of the term, 'surface tension,' a dislike that dates from my undergraduate days in the physical laboratory.

SURFACE-TENSION.

All masses of substances, whether solid, liquid, and probably gaseous also, have, acting at their surfaces, a force parallel to the surface that is the resultant of molecular activity within the body of the substance, and that tends to resist rupture of the surface. This force, in the case of a liquid, is known as 'surface tension.' It is difficult to measure it, but it has been measured for many liquid substances. For the surface of plain water in contact with air, the magnitude of this force has been determined to be 81 dynes per square centimetre.* In all likelihood the figures will be modified by further experimentation, but for any purpose of the engineer this figure is quite accurate enough.

When a slightly oiled needle floats upon the surface of water, the force that causes it to float is 'surface tension.' This force is strong enough to prevent the needle from rupturing the surface; hence, if the needle cannot rupture the surface, it lies apparently on top of the water, or 'floats.'

As to the nature of the manifestation of energy or force, which we call 'surface tension,' the textbooks will give enough to clarify and even confuse, but some attempt must be made here

Encyclopedia Britannica, 11th edition, p. 275.

to render clear what the nature of this force may be. W. R. Ingalls says :* "A body of water, or of any liquid, has greater cohesion in its free surface, *i.e.*, the surface exposed to the air, than elsewhere in its interior, because, whereas the particles in the interior are mutually attracted by adjacent particles in all direc-

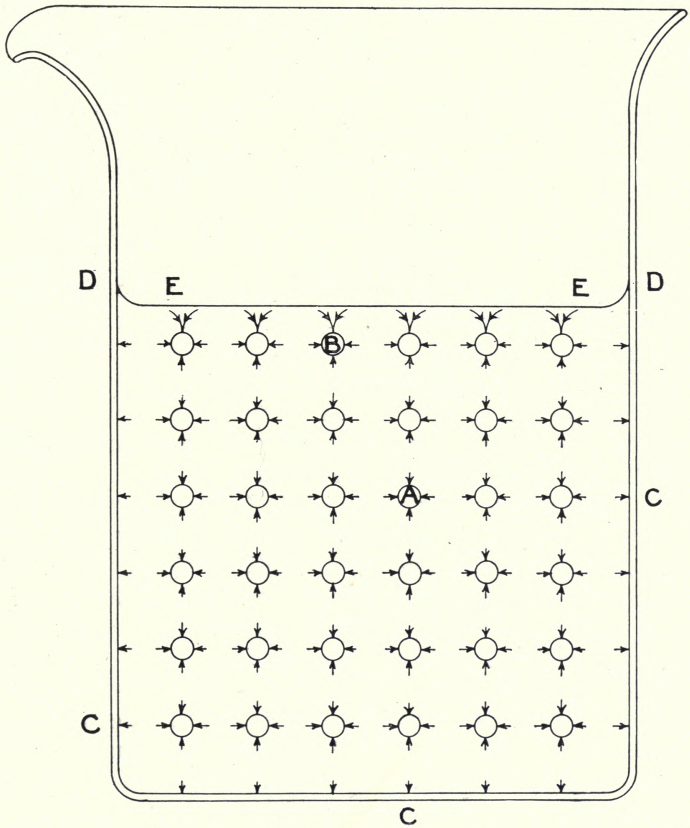


FIG. 5.—Beaker of Liquid.

tions, those which are at the surface have no attractions from the outside—from above, let us say—to counteract the pull from those in the interior." The state of affairs he describes can be illustrated diagrammatically by imagining the molecules of the liqu[illegible] to be of sufficient size to be represented on paper. In Fig. 5

*Eng. & Min. Jour., Oct. 26, 1907, p. 765.

each circle will represent a molecule. The molecular attraction of each molecule can be resolved into resultants for purposes of illustration, the resultants being placed as shown by arrows in the figure.* Now the molecule at A, for instance, attracts and is attracted by adjoining molecules by resultant forces that are equal, and the molecule is free to move in all directions. The molecule at B, however, having no molecule above it to attract and be attracted is in a somewhat different state from the molecule at A. The molecule at B has its upper one of the six resultant forces uncompensated by a molecule lying above it, so we can assume that this upper resultant is compensated between the molecules on any side of B. This gives the topmost row of molecules a stronger attraction for each other than the molecules adjacent to A have for one another. The attraction of the molecules within the liquid, as, for instance, those at and adjacent to A, is known as the force of cohesion. If this force of cohesion is resolved into the six resultants as above described, and its magnitude is called 6 units, then the magnitude of the molecular attraction acting on a molecule in the top layer, as at B, will be 6 units just the same, but the molecule will not be as free to move in every direction as is the molecule at A. If the stress between any two molecules in the horizontal row containing A is 2, then the stress between any two molecules in the horizontal row containing B will be 2½. Ingalls goes on to say in explanation of this : "The "effect of this is to reduce the mobility of the particles on the "surface. The surface, as it were, is stretched by [like] an elastic "skin, the effect being the same as if the surface layer exerted a "pressure on the interior. The production of this 'surface "tension' represents energy, *i.e.*, molecular energy which may "be measured." As we have quoted above, from the *Encyclopedia Britannica*, this surface tension has been determined for water to be 81 dynes per square centimetre, a force that resists penetration from within or without the liquid.

ADHESION.

We must go further afield in the study of molecular forces before we can understand clearly the act of the flotation of particles heavier than water, and consider the molecular phenomenon known

*To make the assumption complete we must imagine two resultants acting at the centre of each circle, at right angles to the plane of the drawing.

as 'adhesion.' Referring again to Fig. 5, at C there are molecules that have uncompensated attractions unless we assume these are compensated by attraction between the liquid and the solid walls of the vessel. But the force of adhesion is also made up in part of the molecular activities of the solid surface molecules, which, we believe, lie much closer together than those of a liquid. The surface activity of a solid would be difficult to measure ; but by analogy we are justified in assuming it is in general greater than the surface activity of a liquid. So that a liquid and a solid in contact should have an attraction for each other in general stronger than the surface tension of the liquid. This state of unbalanced liquid stresses at the bounding surfaces of a liquid also gives rise to a further noticeable condition, as at D, where the corner molecule has not only its upward component, but also one of its lateral components near E abnormally compensated. This will give an illustration of what produces the meniscus, where a liquid, a solid, and a gas come into contact. Adhesion is not, however, limited to solids on liquids, but acts in solid-gas, and probably gas-liquid couples. The mathematics of these forces and the theoretical discussion could be pursued considerably further, but enough has been given to illustrate the terms employed.

The films of gases that are attracted to the surfaces of solid particles adhere strongly in some instances, and are displaced therefrom by a liquid with considerable difficulty. This quality of adhesion varies remarkably with different substances.

With some substances the gas adhesion is strong and the liquid adhesion is weak ; in other words, they are wetted with difficulty. In this class are the metallic sulphides, which, although they have a natural tendency not to adhere strongly to water, do fortunately have a strong natural tendency to adhere to oil. And further, oil has an even stronger tendency to adhere to its gas film, so that a sulphide particle covered with an oil film has an already strong tendency not to adhere to water considerably increased. Quartz and gangue minerals generally, on the other hand, have preference in directly the opposite direction. They have a comparatively feeble adhesiveness to gas films and oil, and a strong adhesiveness to water, and this already strong adhesiveness for water is greatly increased by a slight acidulation of the water. There has been no satisfactory theory yet propounded as to why acid does promote the preferential adhesion of water to gangue particles, and probably

also at the same time the preferential adhesion of oil to sulphides, and for the present commercial purpose it does not seem necessary to do more than record this important fact. Bertram Blount, in speaking of sulphide particles, has expressed the idea of selection or preferential oiling as follows: "Before they were oiled at all their surfaces had certain qualities, one of which is a tendency not easily to be touched by and wetted with water. On the other hand, correlated with that property is the power of being easily touched by and wetted by oil. When they were put through this process they exercised both properties, and acquired or annexed a minute quantity of oil, which was presented indifferently to them and to the gangue, only they obtained it and the gangue did not. They came out of the process with that inherent quality enhanced by a minute film of oil, and then they were even less ready to be wetted by water and to sink through it than they were before, but it was only an exaggeration of what was a native quality."* Kenneth A. Mickle, in an excellent paper,† giving the results of experimental work on gas-bubble and oil attachment, points out that gas-bubble adhesion does not take place if the amount of oil is too large—that is, if the sulphide particles are too much wetted by oil. His paper is the most valuable contribution that has yet appeared on these subjects; but, unfortunately, he has used both the words 'cohesion' and 'adsorption' where he should have used 'adhesion.'

Thus it has been established that there are:

(1.) Forces acting at the surface of a liquid, the resultant of which tends to prevent rupture of the surface.

(2.) Forces acting at the surfaces of all substances, and especially at the surfaces of sulphide particles, that cause films of gases resisting displacement to adhere to their surfaces.

(3.) Forces acting at the surfaces of sulphides that cause these surfaces to show a preferential adhesion to oil.

(4.) Forces acting at the surfaces of gangue minerals that cause these surfaces to show a preferential adhesion to water, and especially acidified water.

We now have the main principles by which to account for the 'floating' of particles heavier than water, and we shall not worry as to what more these forces are, nor discuss the mathe-

*Evidence at trial of B.O.C.S., Ltd., *v.* M.S., Ltd., 1908.
†*Australian Mining Standard*, Vol. XLVII., 1912, pp. 333, 357, 381 & 403.

metical formulas by which they can be resolved into their component parts.

In the simplest case we have a small particle of zinc sulphide, which has been exposed to the air, and upon the surface of which there is adhering a film of air. This particle of blende P, Fig. 6, is then brought into contact with water. The force of adhesion between the particle and the film of air prevents the water from displacing the film of air, and the force of surface tension prevents the particle of blende from penetrating the water surface; therefore the particle is suspended at the surface thus:

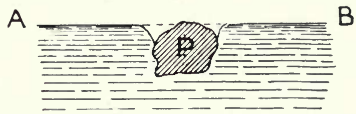


Fig. 6.—Floating Piece of Mineral.

If this particle of blende, P, before being brought into contact with the water, had been coated with a thin film of oil, and if the water had been slightly acidified, then both the adhesiveness of the particle for the gas film and the resistance of the liquid surface to rupture would have been increased, and the act of 'floating' would have been made triply sure by the natural tendency of the blende and the enhancing action of the oil and acid. If at the same time a particle of quartz gangue had been brought into contact with the acidified water surface, it would have behaved in an entirely different manner. The particle of quartz, having a much feebler adhesiveness for its air film, and having a strong natural tendency to adhere to water, and also having this tendency to adhere to water and become wetted with water increased manifold by the acidulation of the water, it would have quickly penetrated the liquid surface and sunk to the bottom, for the act of wetting implies at the outset penetration of the surface.

BUBBLES.

In Fig. 6 it should be pointed out that the surface A B may be either the horizontal surface of a liquid at rest (and considered the limiting surface of a bubble of infinite radius), or, equally important, the surface A B may be considered the surface of a bubble of small diameter within the body of a liquid. This bubble may have a radius of one foot or one inch or one thousandth of an inch, and the action of the sulphide particles with reference to the bubble will be just the same as it is with reference to the

free surface of a liquid. If the bubble has a radius of, say, one-tenth of an inch, and the blende particle a mean diameter considerably less, the bubble will rise by its buoyancy to the surface of the liquid, and carry up with it the blende particle adhering to the surface A B of the bubble. If then, instead of only one blende particle, we mix slightly acidified water with crushed ore and a little oil, and release in the whole body of the pulp a large number of minute gas bubbles, we will have the above described sequence of events taking place in innumerable instances, and these innumerable bubbles will rise to the surface of the liquid and rest there in the form of a froth, carrying with them the sulphide particles, while the gangue in the meantime has exercised its preferential adhesion for the water and become wetted, and remains within the body of the liquid and sinks to the bottom of the vessel. The bubbles may be bubbles of air introduced by violent agitation of the pulp, or air bubbles released from solution in the liquid by subjecting the liquid to a vacuum, or air bubbles dissolved in the liquid at super-atmospheric pressure, followed by a release of pressure, or they may be carbonic-acid gas bubbles released by the chemical reaction of sulphuric acid on carbonates, or in several other ways.

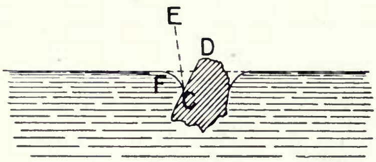


FIG. 7.—The Contact Angle.

In Fig. 7 it will be seen that near C there is a point where the air, the liquid, and the solid all meet in a common point, this point being the trace of a line perpendicular to the plane of the drawing. The angle E C D is made up on one side with the solid and the other side with a tangent drawn somewhere on the curve C F. It is certain that a study of the curve C F, by means of a microscope and screen, would be a profitable line of experimental work. Maxwell says : "The constancy of the angle of contact between the surface of a fluid and a solid was first pointed out by Dr. Young." It is difficult to say where this tangent should be drawn. From a consideration of the forces acting near the region of mutual contact between a solid, a liquid, and a gas, it seems most reasonable to assume that there is no definite point where

one could draw a tangent, but that the curve C F is a continuous curve, the functions of which are : (1) The force of surface tension of the liquid ; (2) the force of surface activity or adhesiveness between the solid and the liquid ; (3) the force of adhesiveness between the solid and the gas ; (4) the force of adhesiveness between the gas and the liquid ; (5) the force of gravity ; (6) temperature ; (7) pressure ; (8) shape of the solid surface ; (9) composition of the solid ; (10) composition of the liquid ; (11) composition of the gas ; and others.

The methods of measuring what are termed contact angles are shown in Fig. 8, a piece of mineral having one plane surface, generally a cleavage plane, being immersed in a liquid surface as at A, and then turned through an angle, α, to a position like B. As the piece of mineral turns, the curved surface of the liquid in the neighbourhood of the line of mutual solid-liquid-gas contact flattens until it is horizontal, and the angle $180° - \alpha$ is said to be the angle of the contact. This angle is a definite angle under fixed conditions.

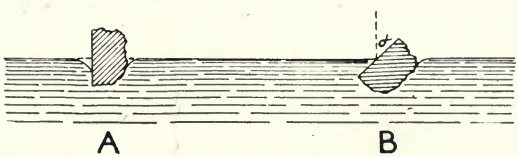


FIG. 8.—Measuring Contact Angle.

H. Livingstone Sulman, in Bulletin No. 79, Trans. I.M. & M., speaking of the angle $180° - \alpha$, announced that "a study of a series of observations on various substances showed a series of curiously discrepant readings, which on further research proved to be due to the existence of a variable range of the contact angle between liquids and solids, though of constant magnitude of variation for each substance. This hysteresis appears to be intimately connected with the ability of a given solid to condense upon itself gas films, and when submerged in a liquid to determine the attachment of a gas when generated. It follows that this angular hysteresis reaches its highest value for minerals that are the most susceptible of flotation. Besides roughly quantifying the gas-condensing power due to the surface energy of solids, it brings us somewhat closer to an explanation of the efficiency of acidification. Whereas the angular hysteresis of silica in plain water may exceed 30°, thus indicating that substance to have a definite power to occlude gas and float, it drops to from 4° to 0° in water acidulated with

sulphuric acid." Sulman has here announced a discovery of the first magnitude, and places in the hands of the physicist a clue to many puzzling questions.

COMMERCIAL EFFECTIVENESS.

The forces with which we are dealing are feeble in magnitude when compared with, say, the force of gravitation. It should be emphasized, however, that although these forces acting at the surface of substances are to our conception feeble, they act continuously at all surfaces; and although we cannot increase the unit force, we do have it in our power to increase enormously the units of surface, and thereby we can bring the nett resultant work of these forces up to an effective sum.

There are two ways in which the surfaces involved can be increased. A cube of ore 2.1544 feet on each edge contains 10 cubic feet. If this ore is a definite mixture of quartz, blende, galena, etc., it will weigh just a ton. The cube will have a total surface area of about 28 square feet, or roughly 4,000 square inches. If this cube of ore is crushed to 40-mesh it is certain, on reasonable assumptions, that the superficial area of the ton of ore is increased to more than 30,000,000 square inches, an increase in area of several thousand times the original.

The De Bavay process uses the surface film of the liquid at rest as the transporting agent, and therefore does not get the advantage of the second method of increasing the surface factor, which is advantageously made use of by Elmore, Minerals Separation, and Potter-Delprat. This second method of increasing the effective surface is by creating a froth of bubbles, each bubble of which acts as previously described. It is no unusual sight to see on the flotation boxes of the Potter-Delprat and Minerals Separation processes two inches of froth composed of a compact arrangement of bubbles and sulphides. By determining, roughly, the size of the bubbles and the distance apart, it is safe to say that the available liquid surface is increased from 20 square feet on the free surface of the liquid in a box to 2,000 square feet when the surface of all the bubbles is counted. In both the case of the mineral and the liquid it is obvious that only a small portion of the surface is used for the work of flotation.

As before stated, the surface tension of water has been determined to be a force of 81 dynes per square centimetre, acting at the surface, to resist penetration of the surface. If we assume

that the force tending to make finely divided sulphides penetrate the surface is the force of gravity, then each gramme of sulphides is impelled to penetrate the surface by a force of 981 dynes, and therefore one square centimetre of the surface will hold up 81 ÷ 981 = 82.6 milligrammes of ore.

Leaving out of account the enhancement of this force of surface tension by the admixture of oil and acid and other means, the following table will show that this force is adequate for the work required of it. The efficiency of the utilisation of the force is in all four cases very low :—

	No. of Machines.	Feet of overflow lip.	Sq. feet of Surface.	Times per min.	Capacity at (81 dynes per sq. cm. = 82.6 mg. per cm.) lb. per hr.	Actual lb. produced per hour.	Actual lb. per hour per ft. of lip.	Actual lb. per hr. per sq. ft. of surface.	Theoretical Capacity lb. per sq. ft. per hour.
De Bavay	88	2765	1620	20	328,800	44,800	16	28	202
Elmore	10	45	6.5	60	3,960	8,064	179	1,240	609
Minerals Separation	6	24	120	3	3,650	31,360	1,300	260	30
Potter-Delprat	3	14	68	3	2,065	26,880	5,376	395	30

Referring to the last two columns, in the case of Minerals Separation, Elmore, and Potter-Delprat, it will be seen that they have increased their theoretical capacity per hour, based on the surface area of the boxes, to several times more actual working capacity by means of making a froth. The variables in the problem are so many that it is not safe to attempt more than to roughly quantify the force available, but it is certain that the force available is many times as large as is necessary for the work to be done. This phase of the subject is an interesting one for research and speculation, and will, no doubt, receive critical study.

SOLUBLE FROTHING AGENTS.

In what has been said before in regard to the production of a mineral froth, I have had in mind the use of some insoluble substance like oil to promote the flotation and froth production. In the Potter-Delprat process a froth is presumably produced without any oil, but in that case carbonic acid gas is the gas used. It is a significant fact that no method has yet been found of producing a mineral froth by air bubbles without the addition of oil or some other substance. Among other substances that will assist in producing a commercially effective mineral froth are a number of soluble substances, as amyl alcohol, camphor, most of the essential oils, the phenols, and a number of gas-tar derivatives.

The phenomena to be observed in connection with the use of these soluble substances as mineral frothing agents are confusing. What has been said about the oil adhering to the sulphides in the first part of this chapter does not apply in the case of these substances, because they are completely soluble in the proportions used; being completely soluble in the proportions used, the small amount employed in treating the ore (1 lb. per ton of ore) cannot be thought to adhere preferentially to the sulphides. On the other hand, although these substances are soluble, the solution cannot be used over and over again beyond narrow limits, but the frothing agent must be added continuously. It is also inconceivable that there is any chemical reaction between, say, the soluble essential oil of *eucalyptus amygdalena* and any of the ingredients of the ore. The froth produced in this case has identically the same appearance as where air, oil, and acid, or acid and carbon dioxide, are the froth constituents, and we are justified in assuming that in the main there is no difference in the forces acting. A complete answer as to just 'What is a froth ?' would probably clear away all the uncertainty as to just 'What is a flotation process ?'

COAGULATION.

One of the most significant facts to be observed in these processes is the coagulation effect of the operation. As an illustration, when a little salt or acid of almost any kind is added to soapy water, the soap collects in flocculent masses ; we say the soap has coagulated. So in this ore-treatment operation it will be observed that the sulphides are coagulated in masses, some of which are of appreciable size even when they have not gathered sufficient air bubbles to float them. The gangue, on the other hand, has not coagulated ; but, due to the fact that the sulphides have coagulated, the gangue assumes an appreciably different and generally lighter colour than was the original ore. If the sulphides have not been floated as a froth (due to insufficient gasification), it will be observed that the ore as it settles has a streaky or mottled appearance, due to the fact that the darker sulphides have coalesced in considerable masses. It is not to be inferred that coagulation is a condition necessarily precedent to successful flotation, for it is not ; but in tests, and in the operation of a working plant, coagulation is a 'sign of good work.'

R. Storm says[1] : "Fine slime cannot be treated by these processes because, as the volume and area of the particles ap-

proach zero, they will have no adhesion effect." This is just where coagulation becomes a factor in rescuing the slime, and, contrary to his opinion, establishes the fact that adhesion does act, and that coagulation is simply one of the manifestations of adhesion. By a process that gives violent agitation with aeration and warming, the slimed sulphides coalesce together in the form of coagules, and then become, if they were not before, amenable to the forces of gas-adhesion and surface tension.

This coagulation of the sulphides is similar to that in the case of butter, when, after a period of agitation of the cream, the butter-fat particles in the cream begin to adhere together, and finally grow into balls of butter of appreciable size, and the dairyman says : "The butter has come." So in the case of an ore-pulp with a small portion of oil added, with or without acid, if it is stirred for a suitable length of time with a rolling motion, the sulphide particles begin to adhere together, and if the rolling motion is sufficiently prolonged, the sulphides can be made to gather together into balls an inch in diameter free from any gangue particles. If this coagulation effect is stopped in its incipient stages, and if a multitude of infinitesimally small gas-bubbles are released in the pulp, each bubble lays hold of a 'coagule' of sulphides and buoys it to the surface where the mixed bubbles and sulphides rest in the form of what we call 'froth.'

CHAPTER V.

TESTS.

From what will be said later in regard to the limited applicability of these methods, it will be evident that anyone undertaking the study for the first time of either the application of the processes to a particular ore, or a study of the theory of the processes themselves, should begin with an ore that is easily treated by flotation. What is needed is an ore that presents the fewest special problems. An ideal mixture for the experimental work of a beginner would be one composed of 60% quartz and 40% brown blende, or say, 70% quartz and 30% of pyrite or chalcopyrite. These mixtures are not common in nature, but approximations thereto occur frequently. With the above proportions in mind as ideal ores for the beginner, it is well to ascertain that the ore chosen does not contain more than 2.5% of calcium carbonate or other carbonates. A series of experiments for the beginner who has had no previous knowledge of the processes can easily be made without special apparatus, and such experiments will serve to illustrate some of the phenomena of concentration by floating part of an ore at the surface of a liquid. At the very outset a standard test should be selected for trying each new ore studied or each new oil investigated. The behaviour of the new material under these standard conditions can then be compared with previous results, thus giving the investigator a point of departure in his explorations. A good standard experiment is 1,000 parts of ore crushed to 60-mesh, 3,000 parts of water, 10 parts of sulphuric acid, and 1 part of oil, all by weight and at a temperature of 70° C. Variations can then be made from these proportions in conformity with the special characteristics of each ore under examination, or the special nature of the oil used, or of any other variable that may be under examination. In beginning the investigation of any ore, the above is a good combination with which to start the first experiment, and then the proportions may be varied by gradual steps until the combination giving the maximum result is reached.

In the following experiments the ore can be weighed in an ordi-

nary balance; the water can be measured in cubic centimetres, calling 1 cc. a gramme; the acid can be measured from a burette, but the oil should be measured by counting drops from a glass tube drawn to a medium fine point, previously having determined by trial how many drops of a given oil go to make up one-tenth and one-hundredth of a gramme, because the preliminary experiments will be with small amounts of materials.

EXPERIMENT 1.

Take	10	grammes of	ore.
	30	,,	water.
	0.1	,,	acid.
	0.01	,,	oleic acid.

Temperature 75° C.

Place these in a test-tube of 75 to 100 cc. capacity; warm contents to about 75° C; close the tube with the thumb, and shake energetically for about a quarter of a minute. The only measure that can be cited for the amount of shaking necessary is to shake the tube until the arm aches. Upon allowing the tube to stand a few seconds there should be decided indications of a separation into layers. At the bottom should be a layer of quartz or gangue much lighter in colour than the original ore; then a layer of gradually settling gangue-slime; then a small layer, gradually increasing, of sulphides dropping through the liquid; then a considerable layer of dirty water; and finally, on top of all, a layer of froth composed of bubbles of air and sulphide particles. By varying the amounts of oil or other ingredient of the mixture a series can be secured for comparative inspection. Some of the froths made with certain oils are of wonderful persistence, and if undisturbed will stand without alteration for months.

The next step is to take a larger vessel, say, a wide-mouthed bottle holding 200 cc., one that can be grasped comfortably by both hands and held in front of the operator with the thumbs over the cork. The shaking must also proceed to the aching point by the energetic use of the arms and shoulders. The charge in a series of tests of this kind will be:

Ore (60-mesh)	30	grammes.
Water	90	,,
Acid	0.3	,,
Oil	0.03	,,

Temperature 75° C.

Shake and allow to settle. By carefully preparing a set of bottles for comparison, or by familiarity with a long range of similar tests, the operator can make a rough estimate as to the result. In both the case of the test-tube and the bottle it is difficult, if not impossible, to get quantitative results.

The question of securing, on a small scale, quantitative results that would bear some known relation to actual milling operations, and at the same time be under ready control as to the various factors, has occupied considerable attention. Small machines built exactly like large machines do not always duplicate the

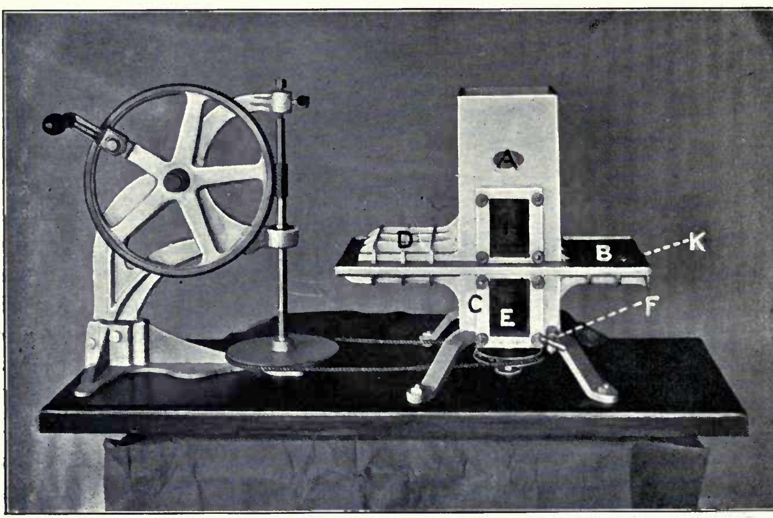


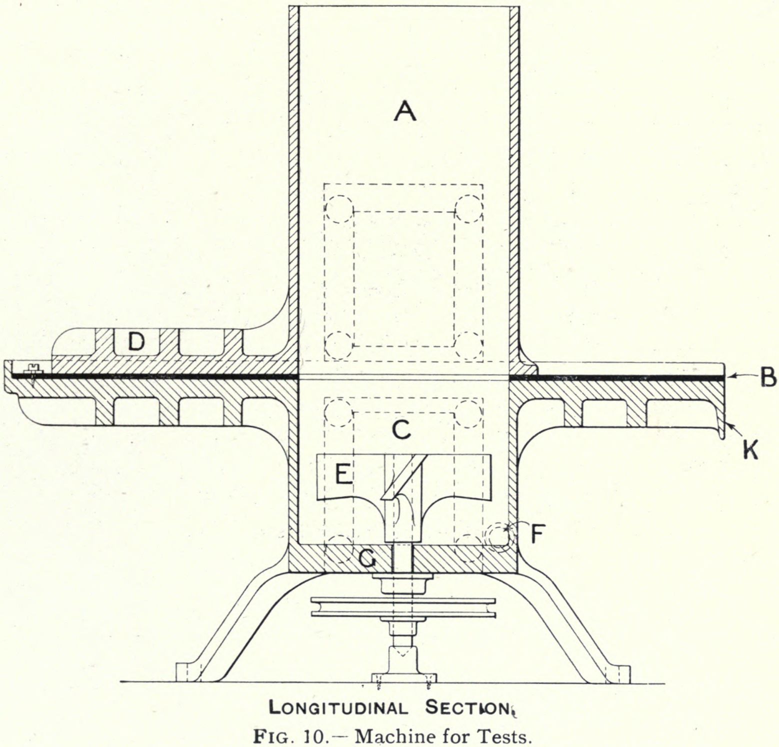
FIG. 9.—Slide Test Machine.

large-scale operations. Perhaps the best all-round apparatus for a study of ores and the influence of oils, acids, temperatures, etc., on surface-tension results is a small machine,* suggested originally by the author to H. L. Sulman and John Ballot, first made by H. F. K. Picard, and improved to its present form by James M. Hyde and others of the Minerals Separation, Ltd., Staff, as illustrated in the accompanying photograph. The driving mechanism to the left of the picture does not require any description, and can with advantage be discarded in favour of a small motor. The motor also

*This machine is not patented.

has the advantage that exact speeds can be duplicated, as well as exact lengths of time of agitation. The portion of the apparatus on the right can be better described by reference to Fig. 10, which is a section drawn through the apparatus parallel to the plane of the photograph. Fig. 11 is a transverse section, and Fig. 12 a plan of the machine.

This machine is made in two parts, an upper one A, and a lower one C, both sliding easily on a rubber cushion B between the two parts, or, better still, having the bearing surfaces highly polished. The rectangular section of the interior is $4\frac{1}{2}$ inches. The upper part



LONGITUDINAL SECTION.

FIG. 10.— Machine for Tests.

A has a tail D, the purpose of this being to prevent leakage of the froth when the upper part is slid to the right for the purpose of removing the froth. Windows of glass in each of the two parts enable the operator to watch the progress of the test. At E there is a simple agitator with four arms at right angles. The shaft driving this agitator goes through the bottom G of the lower part C,

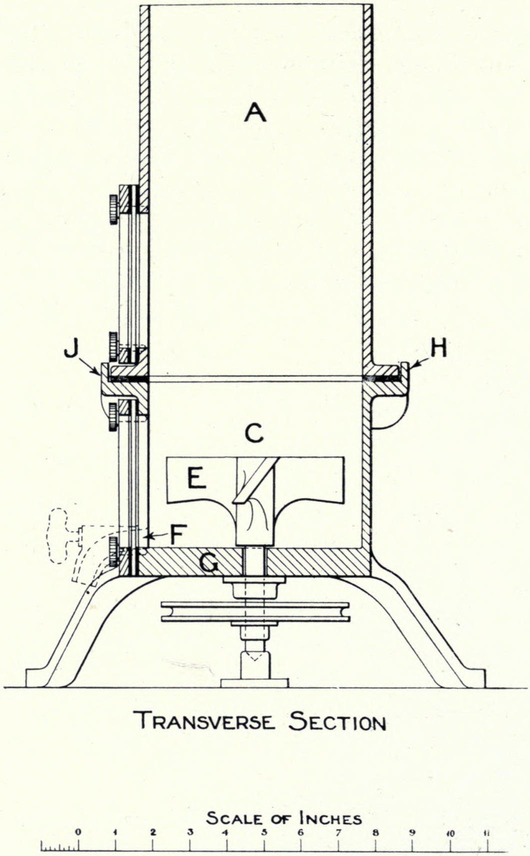


FIG. 11.—Machine for Tests.

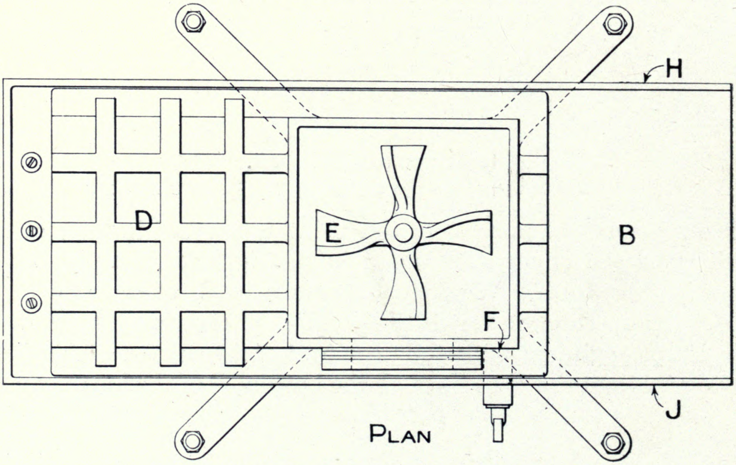


FIG. 12.—Machine for Tests.

and is packed with a small stuffing-gland to prevent leakage. At F is a hole communicating with the interior at the bottom, closed with a valve. This hole is for the withdrawal of tailing. The agitator-arms are 2 inches long from the centre of the shaft, thus describing a circle of 4 ins. when revolving, and so leaving a clear space of ¼ in. wide between the ends of the arms and the sides of the interior. The normal speed of this agitator is about 1,500 r.p.m. The machine should be made of some metal that gives a clear casting. The lower surface of A, which rests on the rubber cushion B, and the upper surface of C, upon which the rubber cushion rests, should be planed and polished smooth. The cushion is a piece of rubber insertion about one-sixteenth of an inch thick, and just wide enough to fill the space between the edges H and J of the tray-like top of C. The cushion can be discarded if the surfaces are accurately planed and polished.

The equipment necessary for the tests will also include a tin boiler, with the proper connections to make steam at a low pressure, the steam being introduced by a tube hanging from the top of the machine almost to the agitator inside. An assortment of agate-ware dishes, burettes, pipettes, etc., is an obvious necessity. Having arranged everything in order, the method of making a test is as follows: Measure 1,500 cc. water and place in the machine. This will fill it to about ½ inch above the bottom of the upper window. There will be no leak at the plane of junction between the upper part A and the lower part C, because the planed surfaces adhere to the rubber sufficiently to prevent leakage under the slight head. Start the agitator at half-speed, and then admit the steam. While the agitator is running, steam in large volume can be admitted without any 'bumping.'* Weigh 500 grammes of properly crushed ore, and put it into the agitating water; test the temperature, and when it is at 75° C add the oil and acid in such quantity as the test requires. Turn on the motor to full speed, and let it run, say, five minutes. Stop the motor and agitator, and let the whole experiment set for one half-minute to allow time for the froth to collect on the surface of the water and for the gangue to settle. If the experiment is a success, the gangue will be much lighter in colour than was the original ore, and will mostly settle to the bottom of the machine, where it can be seen through

*This machine can be cast with a heating-chamber around the lower section, thus enabling heat to be applied by a gas-burner and obviating the necessity for steam.

the lower window. Immediately above the heaviest sandy gangue will be seen the finer gangue and slime rapidly settling. At the bottom of the upper window will be a gradually increasing layer of nearly clean water, and on the surface of the water will be from $\frac{1}{2}$ to $1\frac{3}{4}$ inches of a dense sulphide froth, the amount of froth depending on the proportion of sulphides in the ore and the success with which the experiment is conducted.

The purpose of the peculiar construction of the apparatus will then be apparent, for the upper part A can be slid along the cushion B, carrying with it the froth and that portion of the clean water above the plane of junction of the two parts. When the upper part has been slid to a position where the screws in the right-hand side of the upper window are directly over the lip K, the froth and clear water will run out into a dish placed under K. The tailing, slime, and remaining water can be given a further agitation, but enough water should be added to bring the water up to a line above the bottom of the upper window. After the second period of agitation, a further amount of froth will be formed; this can be removed in a similar manner, and a third and fourth also, if desired. After all the froth has been secured, the tailing, slime, and remaining water can be removed at F, and the two products, concentrate and residue, examined for weight,

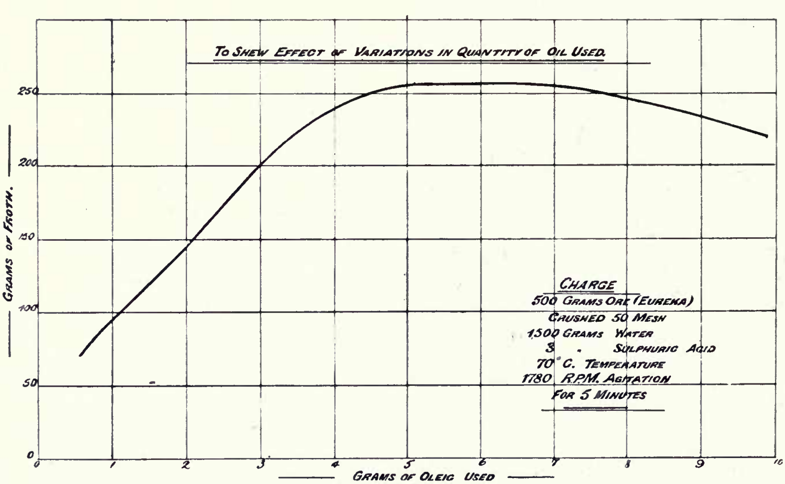


FIG. 13.—Quantity of Oil.

size, or composition. In this machine an average of 20 tests per day

can be made, and the following series is suggested as instructive :

Take 100 lb. of ore crushed to 60-mesh, such as described above as being suitable ; mix thoroughly and put in a dry place for use in the whole series of experiments.

SERIES A

No. 1.—Ore	.. .. ..	500 gm.
Water	.. ..	1,500 ,,
Acid ..	.. ..	5 ,,
*Oil (oleic acid)	..	0.1 ,,

Temperature 80° F.

Agitate at 1800 r.p.m. for five minutes.

Let settle five minutes.

Remove froth, filter dry, and weigh and assay if desired.

2.	Same as No. 1	except	0.2	gm.	oleic acid.
3.	,,	,,	0.3	,,	,,
4.	,,	,,	0.4	,,	,,
5.	,,	,,	0.5	,,	,,
6.	,,	,,	0.6	,,	,,
7.	,,	,,	0.7	,,	,,
8.	,,	,,	0.8	,,	,,
9.	,,	,,	0.9	,,	,,
10.	,,	,,	1.0	,,	,,

A useful series of observations can be secured by simply observing the weights of concentrate produced. More interesting data, however, can be obtained by sizing both the tailing and the concentrate on a standard series of screens and then assaying the sizes. When the results are plotted from the weights of the various concentrates secured in this series, the curve will be of the nature of Fig. 13. This curve shows that for this ore under these conditions the maximum effect is secured with 0.8 gramme of oil. More than that amount is detrimental, which fact would be proved by still further increasing the amount.

*Oleic acid is an oil by-product from tallow candle manufacture, which can be secured almost anywhere.

SERIES B.

No. 1.	Same as Series A, except oleic acid 0.5 gm. and sulphuric acid 0 gm.
2.	Same as No. 1, except sulphuric acid 0.5 gm.
3.	,, ,, ,, ,, 1.0 ,,
4.	,, ,, ,, ,, 1.5 ,,
5.	,, ,, ,, ,, 2.0 ,,
6.	,, ,, ,, ,, 2.5 ,,
7.	,, ,, ,, ,, 3.0 ,,
8.	,, ,, ,, ,, 3.5 ,,
9.	,, ,, ,, ,, 4.0 ,,
10.	,, ,, ,, ,, 4.5 ,,

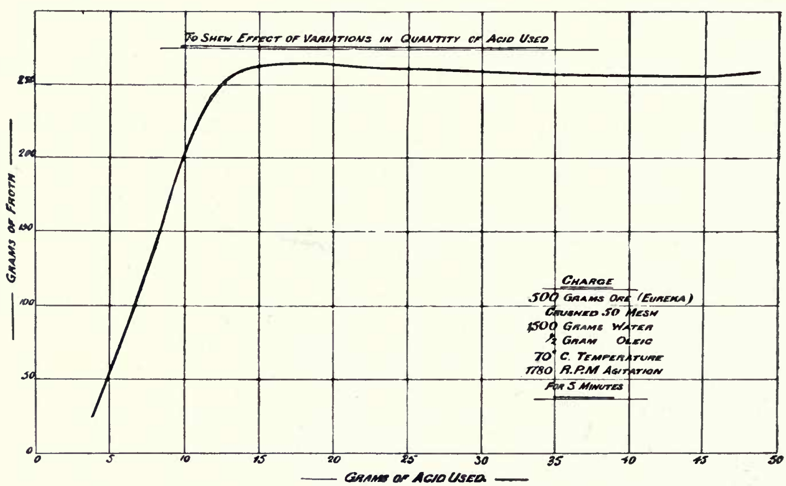


FIG. 14.—Quantity of Acid.

According to the amount of carbonate in the ore, the curve of the plotted results will be something like Fig. 14. This ore needs but little acid, the maximum result being secured with 3 grammes. It will probably be ascertained that if the acid is increased sufficiently the recovery is less, because a point is reached where H_2S gas begins to be evolved, and this gas is generally fatal to flotation.

Other series can be built upon the two illustrations already given by varying at regular intervals the temperature, the proportions of ore and water, the nature of the oil, the length of time of agitation, and the speed of agitation. Then having exhausted the

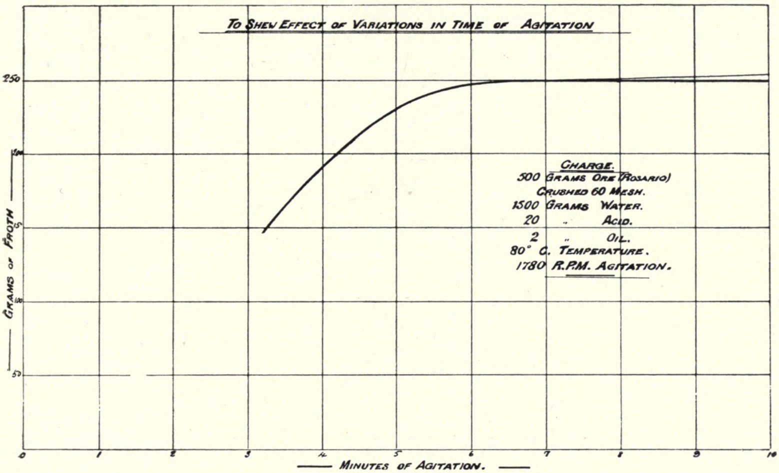


Fig. 15.—Time of Agitation.

possibilities of variation using oleic acid, start a series with a different oil, say, the soluble essential oil of *eucalyptus amygdalena*.

Fig. 15 shows the effect of variations in time of agitation.
Fig. 16 " " " speed " "
Fig. 17 " " " temperature.
Fig. 18 shows the effect of variations in time of agitation with various oils, and also recoveries with various oils.

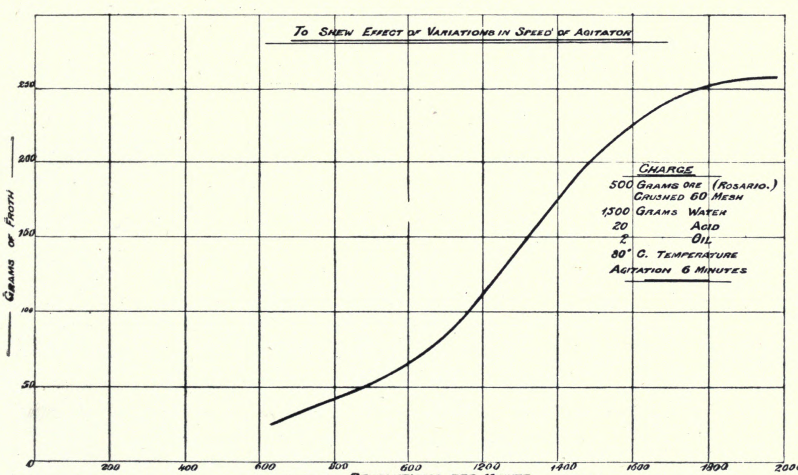


Fig. 16.—Speed of Agitation.

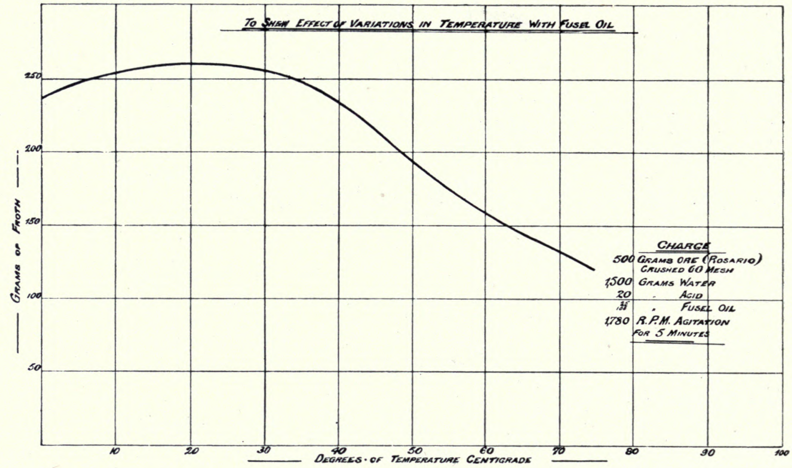


FIG. 17.—Temperature.

The above series of tests, it will be observed, is by means of a process that includes the use of oil and acid and the addition of air by violent agitation. The general principles are the same as in any other combination, and as they are easily applied and approach working conditions, and the results are comparable with those secured in large plants, they are of considerable value. Over a period of four years, when thousands of small tests were made on

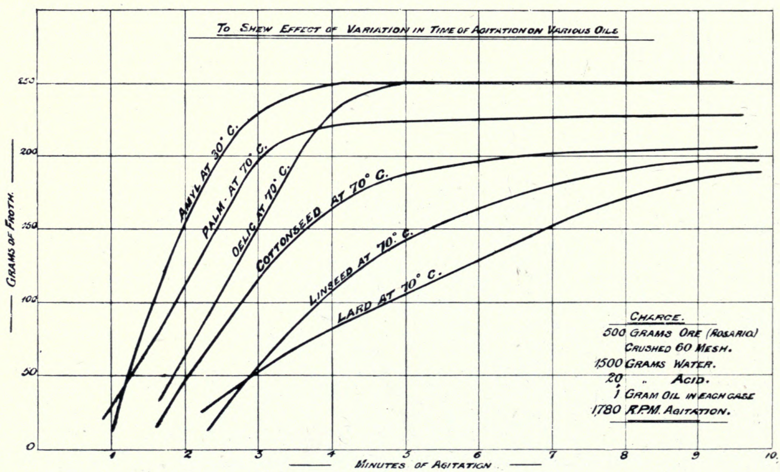


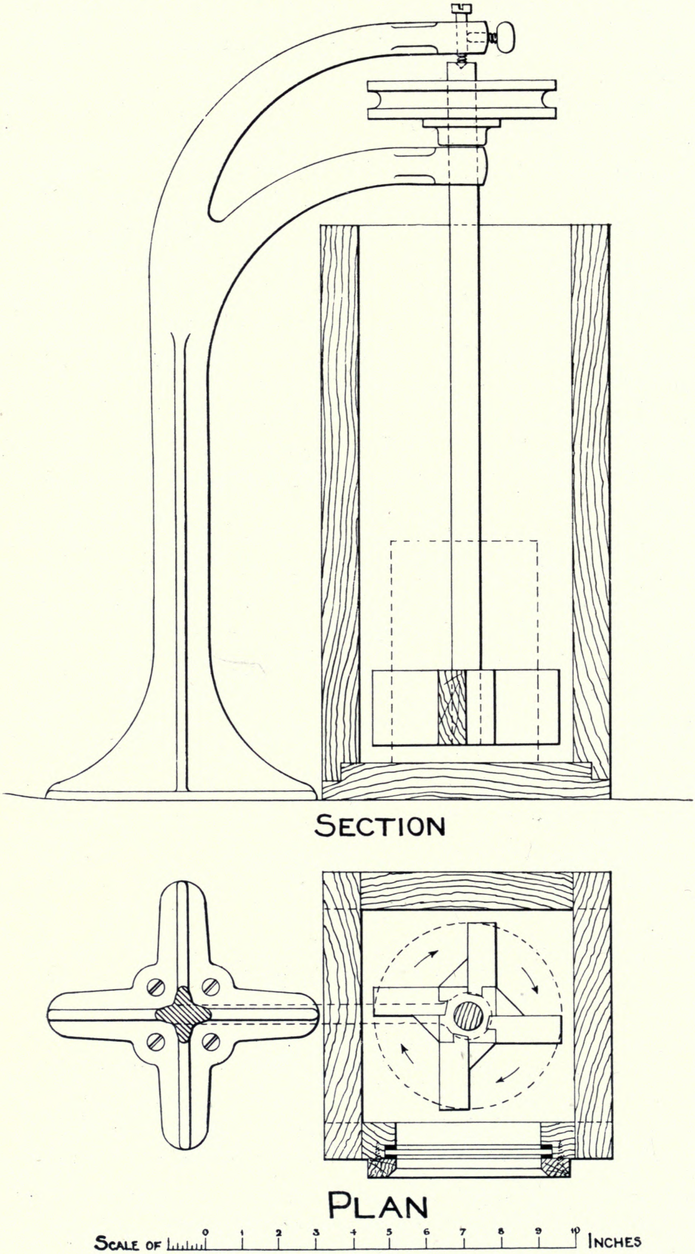
FIG. 18.—Various Oils.

an ore that was being treated in two plants of 1,000 tons per day, the results from the small tests averaged 5% less recovery and 3% lower-grade zinc in the various concentrates than were secured in the large plant.

This machine is a useful addition to the ore-testing laboratory, whether flotation processes are in view or not, because, by the use of it and the expenditure of sufficient acid and agitation, the sulphide contents of almost any ore can be determined accurately.

Another machine of simpler design and cheaper construction is shown in section in Fig. 19, and in plan in Fig. 20. It is made of easily procurable materials, and can be constructed in the laboratory. It has the disadvantage, however, that it requires some skill in removing froth after the agitation. The froth can be removed by careful skimming with a spoon. Some froth will unavoidably be sunk during the skimming operation, but the agitator can be started again, followed by a second skimming. If there appears to be still further chance of a useful result, a third and fourth period of agitation and skimming can be tried. If this machine is made $4\frac{1}{2}$ inches square, inside measurement, and 10 inches deep, it will be the right size for tests on 500 grammes of ore. The equipment necessary for making tests will also include a tin boiler, with the necessary connections for introducing steam into the apparatus. The agitator should be so belted to the motor that it will run about 1,500 r.p.m. The agitator should be about 4 inches in diameter, thus leaving $\frac{1}{4}$ inch clear all round its path of rotation. The method of conducting a test will be just the same with this machine as with the other, except in the matter of removing the froth, and in this instance it will have to be removed by an ingenious hand. Carefully dip as much as possible of this froth off the surface of the water with a large spoon. The design and material of this spoon can be left to the ingenuity of the experimenter, as each man will fancy one of his own invention. Some froth, as said before, will be sunk during the skimming operation, but the agitator can be started and run for one minute previous to another skimming. A third and a fourth, if necessary, will give a fair recovery, provided good mineral-frothing conditions have been established. This machine will yield much instruction, but is not as direct in its results as the one in Fig. 6.

An interesting series of experiments can also be conducted in an ordinary soda-water syphon. The cap of the bottle should be altered so that the pressure can be raised in the bottle with a bicycle



FIGS. 19 AND 20.—Apparatus for Tests.

pump. The necessary alterations are quite easily done, and can be effected in the laboratory. The charge will be 100 grammes of ore, 300 gm. water, with acid and oil to suit. The air-pump should be one with a pressure-gauge attached, so that pressures can be noted. After pumping to 30 lb. pressure, the bottle with the charge should be shaken a few times, so that the air will dissolve. Then the lever being depressed, most of the charge can be drawn into a beaker, and the froth and tailing examined at will. It is worth noting in this connection that excellent mineral froths can be made at normal atmospheric temperature.

FURTHER TESTS ON OTHER PROCESSES.

The processes are so intimately related that it is difficult to give tests serving clearly to differentiate them. Laboratory tests to determine whether any result will be produced can be easily tried without any special apparatus.

TEST FOR POTTER PROCESS.

Take a 200 c.c. beaker and place therein 100 cc. of 3% H_2SO_4 solution. Place this in a water-bath, and raise the temperature to as near boiling point as possible. Stir into the solution gently 30 grammes of ore crushed to 50-mesh. The froth composed of sulphides and CO_2 gas should form at once on the surface of the liquid if the ore is adapted to the process. If the ore contains no calcite or other carbonates, there will probably be no result. In the latter case, of course, a result can be secured by adding to the ore 3% of ground calcite before stirring it into the solution. The concentrate can be removed with a spoon.

The test-tube experiments that formed the basis of the Goyder & Laughton invention are interesting and instructive. Goyder observed that "when heating some Broken Hill sulphides* in a test-tube filled with dilute sulphuric acid, the bubbles, with their sulphide load, travelled to the surface broke, and then fell back again. By inclining the tube as in 2, Fig. 21, the sulphides rose and travelled up the smooth side of the tube until they met the surface, when, as before, the granule of sulphide fell off, but this time it fell vertically until it met the side of the tube, down which it glided. The inference was that if there was a pocket in the under-side of the sloping test-tube the sulphides should gather

*'Australian Mining and Metallurgy,' Donald Clark, p. 397.

in the pocket." A special test-tube like 3, Fig. 21, is easily made, and a number of interesting experiments can be conducted by trials of different ores at varying temperatures and varying strengths of acid.

TEST FOR DELPRAT PROCESS.

The procedure in this case is identical with that above outlined for the Potter process, except that the solution is made from acid salt-cake. This obviously is only different from the preceding test in that, besides sulphuric acid, there is present in solution a portion of sodium sulphate. Most of the acid sodium sulphate on the market is made by mixing strong sulphuric acid and sodium

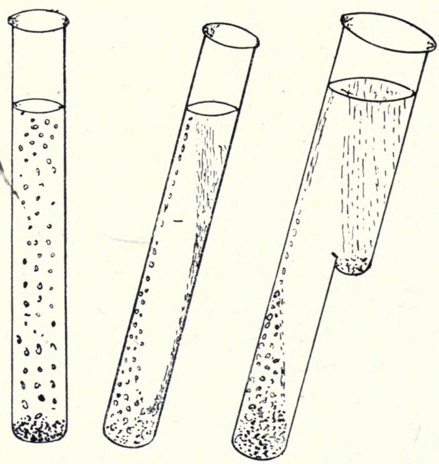


FIG. 21.—Tube for Potter-Delprat Tests.

sulphate in the proportion of about 7 of acid to 3 of sulphate. If there is no carbonate present in the ore, the same result will be secured and the same remedy found efficacious, as with the Potter process.

TEST FOR DE BAVAY PROCESS.

This process depends on a film of sulphides formed on the surface of water to effect a separation. Take 100 cc. of water, containing about 0.1% H_2SO_4; add to this 30 gm. sulphide ore crushed to 50-mesh; add a few drops of petrol, and stir with glass rod for half-minute. Empty pulp on a vanning plaque, and gently

rock the plaque so that the liquid alternately covers and uncovers the ore. As these little waves cover and uncover the ore the sulphides are picked up, and float upon the surface. With patience a clean tailing can be produced.

TEST FOR MACQUISTEN PROCESS.

Take 30 grammes of sulphide ore on a vanning plaque. Add 100 cc. water and a few drops of sulphuric acid. Subject the ore to the same manipulation as in the case of the De Bavay and a similar result will be produced, but much less float material will be secured. No amount of patience will serve, however, to produce a clean tailing. This test serves merely to show the principle on which this particular process works.

TEST FOR ELMORE PROCESS.

What is known as the old Elmore process may be tried in a glass jar of about 1,000 cc. capacity. What is known as a Mason fruit-jar with a screw-top is the best apparatus for this trial. Place in the jar 300 cc. water, 100 gm. sulphide ore, and stir slightly to make a uniform pulp ; add half cc. strong sulphuric acid and 200 cc. thick oil, such as the thick tarry residue of petroleum or a cylinder-oil. Screw on the top of the jar and turn it end-for-end about 20 times, and set aside to settle for a few minutes. The contents of the jar will settle into layers ; at the bottom a layer of sand mixed with some sulphides ; next above will be a layer of muddy water, and above that again will be a layer of oil containing most of the sulphides (the amount depending on the success of the manœuvre) and some gangue. The oil layer may be removed by adding more water carefully beneath the oil through a tube, and after the oil and sulphides have been removed the sulphides can be separated from the oil by heat and gentle stirring, when the sulphides will settle to the bottom.

The new vacuum process is more difficult to test in a small way so as to produce a satisfactory result. Probably the best method is as follows : Take a large-mouthed 300 cc. bottle, and fit a stopper with a tube to be attached to a laboratory suction-pump. Put into the bottle 30 gm. sulphide ore, 100 gm. water, one-fifth cc. Texas or California fuel-oil, and one-fifth cc. H_2SO_4. Stir with a glass rod until a uniform pulp is produced, but do not beat any air into the pulp. Place the stopper in the bottle and attach to the suction-pump. Start the pump, and gently shake the bottle to

keep the ore stirred a little. As the vacuum is produced the sulphides should begin to rise to the surface and form a layer of froth.

MECHANICAL AGITATION.

A simple laboratory experiment will give a clear idea of the efficiency of this method of providing gas bubbles for the purpose of flotation. Take in one hand a test-tube half full of distilled or ordinary water. In the other hand take a test-tube of distilled or ordinary water, to which has been added the smallest possible drop of any one of the following substances: Oleic acid, kerosene, amyl alcohol, any of the essential oils, camphor, or alcohol. Taking one of the above test-tubes in each hand, shake them violently at the same time and to the same extent. The water in the test-tube that had the drop of foreign substance added to it will, upon ceasing the agitation, be white with occluded air-bubbles of small size, and, depending on the substance used, these bubbles and the milky appearance will last for some time. The water in the other test-tube will, however, show no such appearance; the water is as clear and unclouded in appearance as before shaking. An interesting series of tests can be made in this way, in which the time factor for complete clearing away of the milkiness can be observed. This series of tests will show that those substances which produce the best and the most persistent milkiness are in many instances the best materials to use in flotation processes. There are some remarkable exceptions to this rule, however, and some of the worst substances that can adventitiously be introduced into flotation-concentration work, as it is understood at present, are excellent producers of air-occlusion.

DELETERIOUS SUBSTANCES.

A beneficial study can be made of substances deleterious to mineral-froth formation. Having performed an experiment as above described to the point of having secured a froth of, say, one inch depth, one cubic centimetre of a solution of saponin, of a strength of one of saponin to one million of water is added, and then the agitation is started. It will be observed that the froth will have completely disappeared, and cannot again be reproduced. Probably one pound of saponin introduced into the operations of the largest oil-and-gas flotation plant in the world would completely suspend all useful results for a week unless all traces of the saponin were completely removed by complete rejection of all the water

and ore that had become contaminated with saponin, and the plant would probably require a thorough scrubbing with clean water besides. Many other substances have the same effect (though not so pronounced for the small amounts used); among them are glue, starch, flour, tannin, and ox-gall. On one occasion R. Gilman Brown, consulting engineer to a mining company using the Elmore process, described a peculiar aberration of the process. On a certain day the process discontinued working for no apparent reason, and it seemed impossible to ascertain the trouble. No concentrate was produced for several shifts. He investigated to determine whether the water could contain anything deleterious, and noted that these erratic results had begun after they had changed from the ordinary brook water, which had become exhausted in the dry season, to water that had been stored in a series of small lakes and ponds in a peaty marsh. He found that there was probably enough tannin or analogous compound in the marsh water to destroy flotation, especially if the water was brown. The water was at once changed, and no further trouble ensued.

PROBLEMS SUGGESTED FOR RESEARCH.

There are a number of problems, some already mentioned, that will repay scientific investigation. A few are here mentioned:

What is the significance of the hysteresis range in the contact angle between the rising and falling meniscus?

What is the real function of acid in flotation processes?

Can a feasible scheme of flotation treatment be devised for carbonate ores?

Can a non-acid flotation treatment be devised?

What is the significance of the fact that a too strong acid medium in oil-and-gas flotation methods is fatal to good work?

Why are some of the substances that produce good air-occlusion bad flotation-concentration reagents?

Why will air not replace carbonic acid gas in the Potter process, all other conditions being equal?

What is a froth?

Would some method of producing coagulation without the aid of acid and oil enable one to introduce directly the gas-film adhesion-factor, and so secure flotation without oil or acid?

CHAPTER VI.

The Potter-Delprat Process.

The inventions which form the basis of this method were the work principally of two men working entirely independently—Charles V. Potter and Guillaume D. Delprat. It is another in a long line of instances where two minds arrived at practically the same scientific point simultaneously. The ideas are so similar that litigation soon developed; but, unlike many engaged in the development and application of metallurgical patents, these people soon wisely compromised. Potter had priority of patent date, and the slight differences between their processes, it must be admitted, would put a judge in a quandary. The basis of compromise was that Delprat was free to use the process in Australia, while the Potter Sulphide Company acquired all the patents and the right to license the use of the process. The amount asked for royalty in the past was 2s. 6d. per ton of concentrate, which amounts to about one shilling per ton of ore of the Broken Hill type.

After what has been said of the general theory of flotation processes, it is not necessary to give *in extenso* the whole of the principles set forth in Chapter IV. The Potter-Delprat is one of the processes making use of surface-tension phenomena. The act of flotation is accomplished by virtue of the natural adhesion of carbon-dioxide gas bubbles to particles of sulphide, and the result of the manipulation to which the material is subjected is the formation of a dense froth of bubbles and mineral, which floats at the surface of the apparatus. No substance other than acid is used in the process, as in most of the other processes for the purpose of enhancing the adhesion of gas films, but there may be organic substances in the ore which, upon the addition of acid, yield gummy organic compounds that selectively adhere to the ore. It is difficult to understand the working of this process without some such theory to account for the gummosity of the concentrate. It is worth noting that this process is the only one that secures flotation by the buoyancy of carbon dioxide gas, all the others claiming to use ir alone as the active flotation gas. To differen-

tiate from the other flotation processes this one may be called an 'acid-flotation process,' or more correctly a 'carbon-dioxide gas-flotation process.' The gas is generated in the pulp by the action of hot dilute sulphuric acid, or acid salt-cake, on the carbonates which occur naturally in the gangue.

This process, as in use at the Broken Hill Proprietary mine, treats the tailing from the lead-concentrating mills. The tailing assays roughly 20% zinc, 6% lead, and 6 oz. silver. The gangue is a mixture of quartz, rhodonite, and garnet, with about 3% of calcium and iron carbonates. The last-named are of prime importance in the process. The material to be treated is taken from the

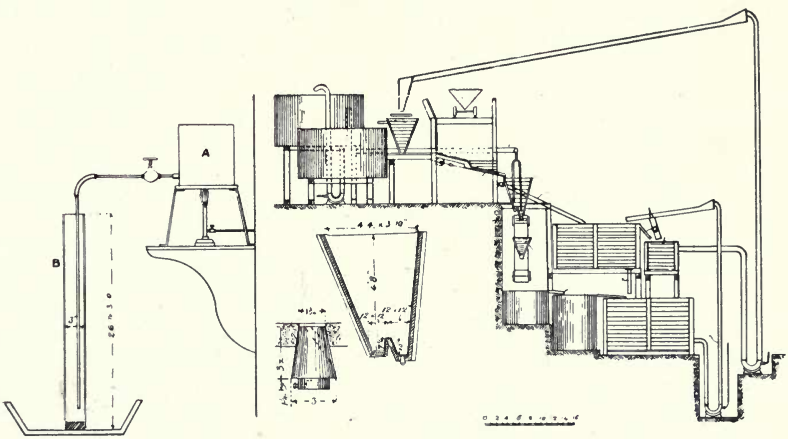


FIG. 22.—Section of Potter-Delprat Plant.

dumps and re-crushed to about 40-mesh in grinding-pans. After removal of the water used in crushing, the material is hauled to the treatment plant, where it is delivered into bins (see Fig. 22)*.

From these bins it is fed automatically into flotation vats, where the separation takes place. These vats are inverted wooden pyramids (see Fig. 23), lined with sheet lead. It will be noticed that these vats have two pockets at the bottom—one with and one without an outlet. Iron pipes introduce the solution into the vat close to the bottom, and so aid in stirring the material. One of these pipes discharges into the blind pocket A, and the

*A paper, read as a presidential address, by G. D. Delprat, before the Australian Institute of Mining Engineers, and published in its 'Proceedings' for Sept., 1906.

other into the pocket with an outlet. The blind pocket collects all heavy stones, bolts, nails, etc., which otherwise would obstruct the outlet. A 2 to 3% solution of sulphuric acid is introduced into the vat at a temperature of 82° C., but as the quantity introduced is more than can run through the bottom outlet, a large

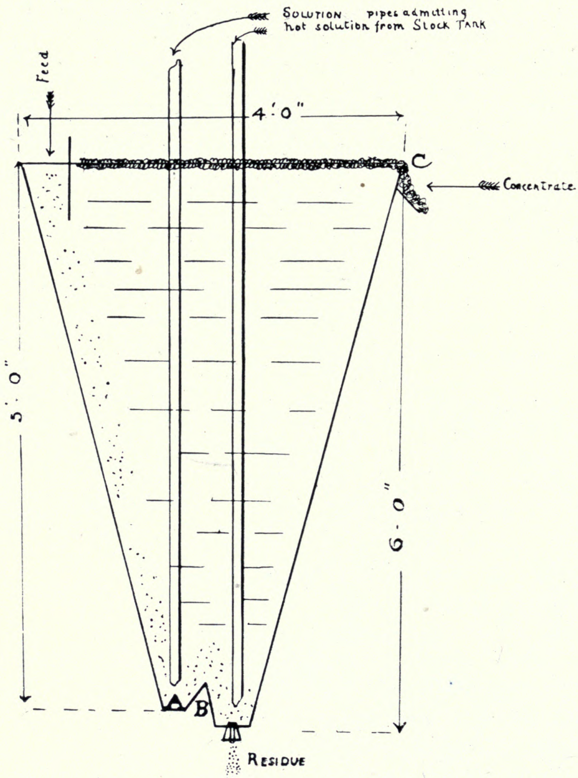


FIG. 23.—Potter-Delprat Frothing Box.

quantity passes over the top by an overflow specially arranged for this purpose. The tailing is then fed mechanically from the bin into the vat, above the blind pocket. As the material falls into the pocket it is washed over the partition B, which separates the two pockets, and the gangue passes away through the outlet. On its way down the vat, however, the acid acts on the carbonates contained in the ore, and produces bubbles of carbon dioxide gas. This gas shows a selective action, and adheres to the particles of

blende and galena, but not to the particles of gangue. The adhering bubbles cause the particles of blende and galena to float ;

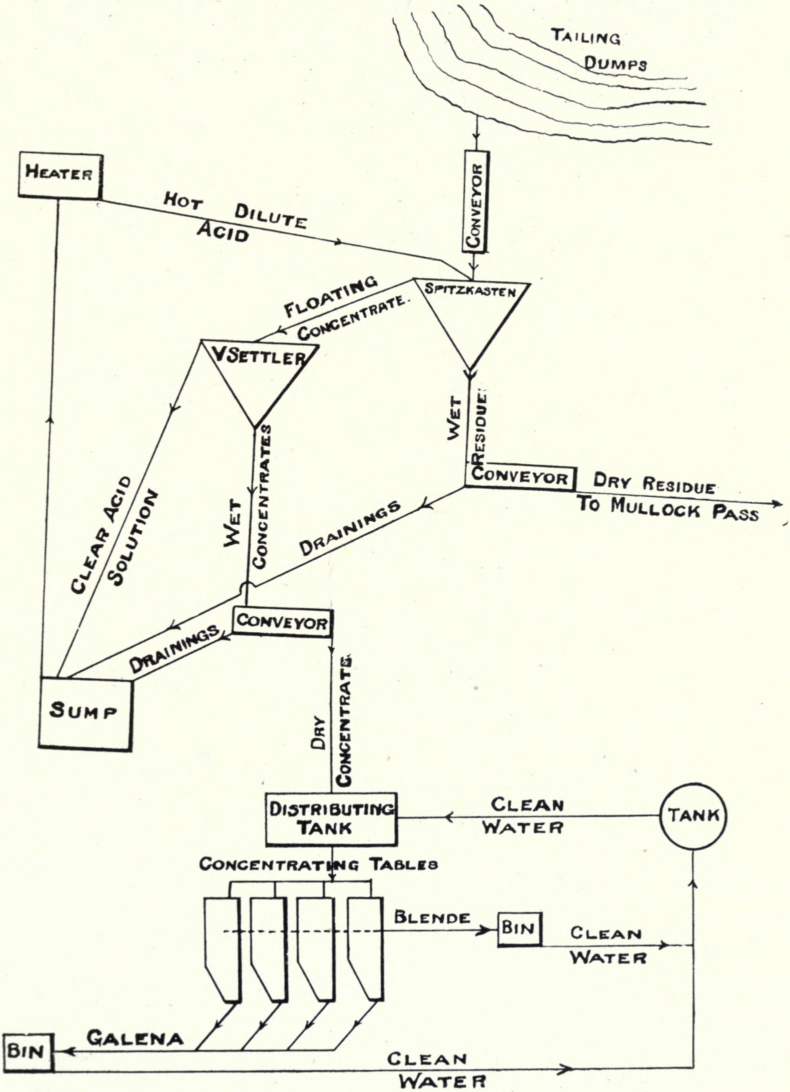


FIG. 24.—Flow-Sheet Potter-Delprat Plant.

they come to the surface in the form of a dense froth, and are washed away by the current over the lip C.

The overflows of all the vats pass to one launder, which discharges into a set of wooden tanks, where on cooling the particles of blende and galena lose their bubbles of gas, and fall to the bottom.

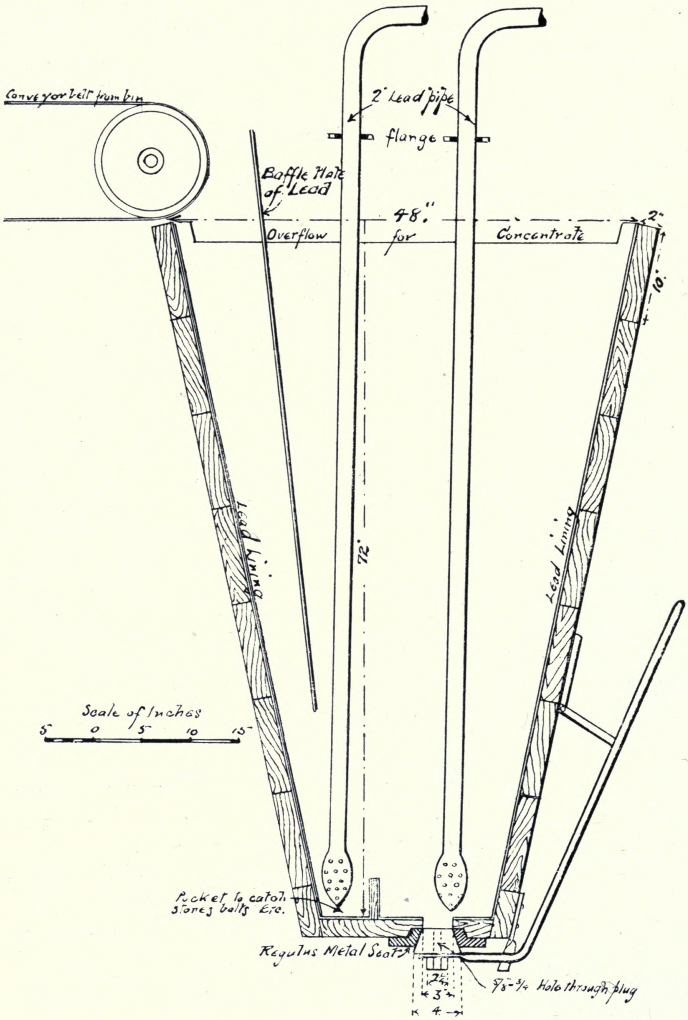


FIG. 25.—Potter-Delprat Frothing Box.

When the tank is full, another tank is filled while the contents of the first is being drained, washed with clean water, drained again, and finally loaded into railway trucks. A flow-sheet for the process

with the re-treatment of the concentrate is shown in Fig. 24.

It is found that each flotation vat can treat from 10 to 12 tons of material per hour, but three vats are generally used for this amount. The speed depends greatly on the fineness of the material. About 200 tons of concentrate is the daily product of three units, but as much as 300 tons per 24 hours has been produced by each flotation vat. Another form of vat for the same process is shown in Fig. 25.

The bottom outflow from the vats carries all the gangue with it. The solution and gangue together fall on a 3-ft. india-rubber travelling belt, with side rollers to make it into a trough. The belt runs uphill, by which means the solution is separated from the tailing and run into a sump, while the solids settle on the belt. On the arrival of the tailing at the end pulley of the belt it is sufficiently dry to be used as filling for the underground workings of the mine.

The temperature most suitable is 80° C. ; in order tor each this, superheated steam at 260° C. is introduced into the solution vats, which stand on a high enough level to command the whole plant. Air-lifts are used to return the spent solution from the drained tailing and concentrate to the solution vat. One treatment only is given the material in this process, and in this regard the process has an advantage over several of the others which require repeated treatments to secure commercial recoveries.

As there are no moving parts in the plant, except the mechanical feeders and travelling belt, the cost of repairs is small. Two engines of 10 h.p. each supply all the power required, except that required for the air jets.

It was found in the experiments conducted by the Zinc Corporation that the addition of some substance that would produce a coagulated appearance to the pulp was of material benefit. Among other substances tried was resin, but the best substances for the purpose of producing this effect would be oils. This brings us back to the question of the enhancement of the inherent quality of the sulphide particles to adhere to gas films by coating the sulphide particles with films of oil, and shows the near relationship of all the flotation processes. Recent Potter patents have sought to cover this idea. It has been said that the present users of this process do not use any oil in their operations, and when I visited the plant on the Proprietary mine none was being used. At first glance it would appear that the concentrate from this process

would be readily amenable to re-treatment by concentrating tables; but the Zinc Corporation found that the concentrate had a 'gummy' or sticky' quality, which rendered such an operation extremely difficult. This is surprising, as the sulphuric acid or any of the salts derived from its use are apparently sufficiently soluble in the table water to render the sulphides loose and sandy. The explanation may be that the hot sulphuric acid forms with the organic matter, which is always present in tailing heaps, insoluble 'gummy' or 'sticky' compounds which exercise a preferential adhesion to the sulphides.

The apparatus and equipment of this method has arrived at a state of finality that some of the others have not reached, the reason being the great simplicity of the idea involved. The cost of the plant is obviously low. The equipment is such that it can be built on the spot from easily procured materials. Ordinary timber, with sheet lead for a lining of the flotation-boxes, is all that is needed. The cost per unit should not exceed £200, including installation.

In the early development of the process, difficulty was encountered in finding a machine or flotation-box that would save the concentrate, the trouble being that the bubbles would break and drop their load. This was overcome by Goyder & Laughton in a machine having a series of traps. Later, when it was discovered that a froth prevented the bubbles breaking, it was an easy step to see that if the flotation-boxes were crowded to a high capacity the froth itself, if produced in sufficient quantity, would act as a blanket, and so prevent the troublesome breaking of the bubbles.

APPLICATION.

BLOCK 14.—The first plant was erected at Broken Hill, on the Broken Hill Proprietary Block 14 company's mine, in 1903, to treat middling from the lead-concentrator. Aside from the small amount of zinc concentrate produced by the Sulphide Corporation by magnetic concentration, this marks the beginning of the Broken Hill zinc industry. The first machines installed were of the Goyder & Laughton type, which were of complicated design and low capacity. In 1904 the Delprat pan (Figs. 23 and 25) was introduced instead. After 1905 this plant was shut down owing to lack of material for treatment. Fig. 25A is a flow-sheet of this plant.

PROPRIETARY.—Concurrently with the above plant, in 1903, the Broken Hill Proprietary installed the Delprat process, the inventor—G. D. Delprat—being the general manager of the mine. This plant in 1904 was treating 3,500 tons per week, which was

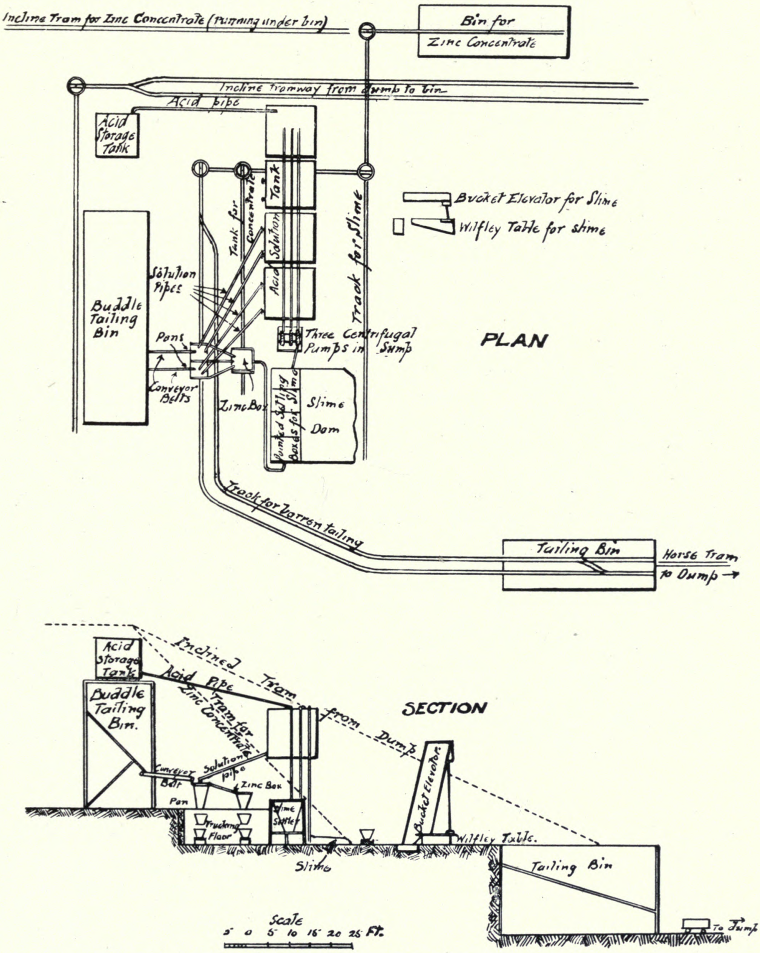


FIG. 25A.—Flow-Sheets, Block 14, Potter Plant.

increased to 5,500 tons in 1905. During 1906 the plant treated 235,000 tons, and a system was installed whereby the material from the dumps was first sent to tables to recover some lead, de-slimed to provide material for sintering, and then re-ground for

the flotation process. Litigation had begun between Potter and Delprat, but was settled in 1907. By the end of 1907 this plant had produced 180,000 tons of zinc concentrate. The plant worked steadily during 1908, and produced 65,000 tons of concentrate. For five months of 1909 it was idle because of the strike, but in the remaining time produced 52,000 tons of concentrate. In 1910 the production was 70,000 tons, and in 1911 92,000 tons. The total production has been 459,000 tons of concentrate from over 2,000,000 tons of tailing treated.

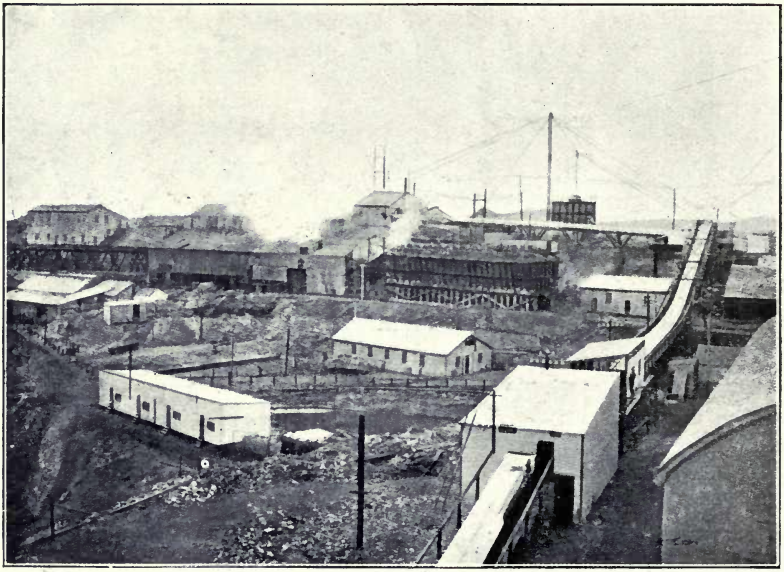


FIG. 26.—Proprietary Flotation Plant.

Figs. 26 and 27 are photographs which give some idea of the magnitude of the operations. The concentrate assayed nearly 46% zinc, 8% lead, and 13oz. silver per long ton. During the first half of 1910 the plant was re-modelled at a cost of £8,000 by the introduction of cast-iron flotation-boxes, presumably of the same design and principle as those shown in Figs. 23 and 25, and by the introduction of conveyors from the heaps and steam-shovel excavators.

For several years it was not possible to treat slime by this method, but an ingenious idea of E. J. Horwood has solved the

difficulty. He found that as the slime contained a large amount of finely ground calcite, the carbon dioxide gas was generated too rapidly, and the bubbles grew too fast to effectively attach themselves to the sulphides. He therefore introduced a centrifugal pump between each two of a series of separating boxes for the purpose of mechanically breaking the bubbles to small size. This violent agitation also, no doubt, assisted in coagulating the slimed sulphides; this, together with the breaking up of the bubbles, enabled the frothing to proceed on this material as easily and perfectly

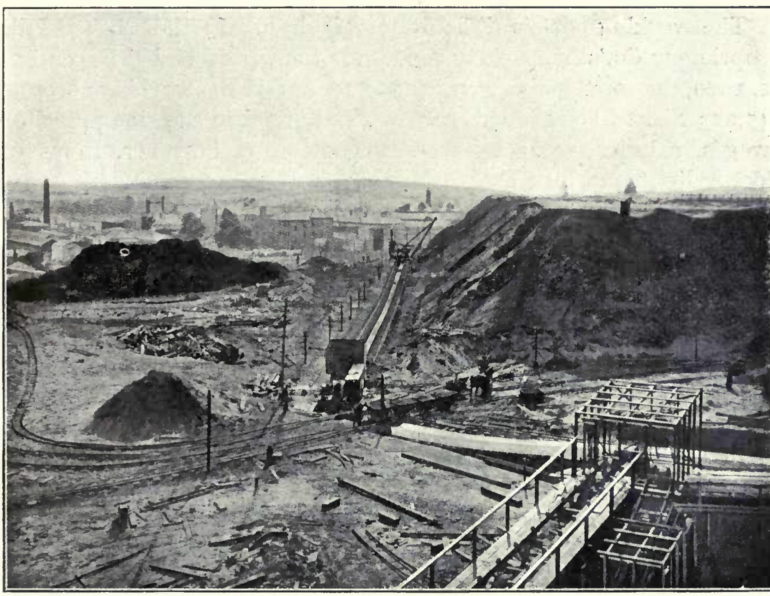


FIG. 27.—Zinc-Tailing Heaps.

as upon any other class. A plant is now in operation which produces about 1,000 tons per month of concentrate from material 90% of which will pass a 200-mesh screen.

ZINC CORPORATION.—In 1905 this company began its operations by an installation of the Potter process on the British mine, where they had purchased a large dump of tailing and middling. This plant was intended to treat 2,000 tons per week. The plant ran intermittently through 1906, with many alterations, and finally the process was abandoned.

Gillies.—The Gillies company purchased a large dump on the Block 10 mine, and erected a plant in 1906 with an estimated capacity of 2,000 tons per week. In 1907 this plant produced 7,700 tons of concentrate during the periods when it was being altered, but finally the Potter process was abandoned, and after a short trial of the Minerals Separation process the plant was dismantled and the tailing sold.

WORKING COST.

The working cost is difficult to calculate. In the Broken Hill Proprietary Co.'s half-yearly report for the period ended December 31, 1910, the tonnage is given as 179,713, and in the working account £45,213 18s. 1d., or 5s. 0¾d. per ton, is charged to the zinc plant for 'wages, salaries, and expenses.' There are, however, items of electric light, machine shop, assaying, electric power, experimental account, fire account, fuel and fluxes, water, locomotive traction, and horses and drays, a portion of which should be charged to the zinc treatment. The previous half-yearly report gave 103,792 tons treated at a cost for 'wages, salaries, and expenses' of £44,999 19s. 4d., or 8s. 11d. per ton treated. The same list of other items was also given. It is a hopeless task to obtain the actual working cost of the process from these reports. We can, however, arrive at one useful deduction, namely, that 30lb. of acid was used per ton treated. The average market price of acid in Broken Hill is about one halfpenny per pound, so that the cost of acid was 1s. 3d. per ton of material treated. The sum of £4,846 was spent for water during this period. As water costs 5s. per 1,000 gallons at Broken Hill, this means 19,384,000 gallons of water was used in the operations. About 100 gallons of water per ton is the loss at Broken Hill, and these figures fit sufficiently well to justify the inclusion of 6d. for water. The heating of the pulp to 82° C. is also a charge which can be accurately deduced from a knowledge of local conditions, and amounts to nearly 6d. per ton. The power charge is practically confined to the items of pumping solutions and elevation of pulp. This charge cannot be ascertained from the published reports; an estimate would be 3d. per ton. Tabulating these and other items, the following table gives the items which concern the actual process itself, excluding all the expense of tramming, de-sliming, and grinding:

	s.	d.
Power		3
Acid	1	3
Supplies		2
Labour		4
Fuel		6
Assays		1
Water		6
Superintendence		1
General		3
	3	5

The acid would actually cost the company less, but is charged at ½d. per lb. for the purpose of comparison.

RECOVERY.

In the report for the last half of 1910 figures are given from which a fair idea of the recovery can be obtained. To do this it will be necessary to assume the metal content of the material treated. There are no authoritative figures relating to this, except in the Annual Report of the Department of Mines of New South Wales for 1904, where the Proprietary company is said to have 2,500,000 tons of tailing assaying 17% zinc, 4% lead, and 6oz. silver per long ton. This, it is believed, is too low. Using these figures, the recovery and products are as follow :

		Assay			Content		
	Tons	Zinc	Lead	Silver	Zinc Tons	Lead Tons	Silver Oz
Feed.........	179,713	17.00	4.0	6.00	30,551	7,189	1,078,278
Concentrate	43,907	46.06	6.3	12.49	20,224	2,766	548,398
Tailing ...	135,806	7.70	3.3	3.90	10,327	4,423	529,880
Recovery % ...		66.2	38.5	50.9			

Ratio of concentration 4.1 to 1

For the six months ended November 29th, 1911, 137,249 tons was treated, yielding 3,136 tons of lead concentrate assaying 54% lead and 28 oz. silver, and 48,192 tons of zinc concentrate assaying 45% zinc, 7% lead and 13 oz. silver. The concentrate being produced now assays 47% zinc.

CHAPTER VII.

The De Bavay Process.

This process is the result of the researches of A. J. De Bavay. The patents are owned by the De Bavay Sulphide Process Company, which lets the use of the process on a royalty. By a recent combination with the Minerals Separation, Ltd., these patents have been merged with those of the latter company.

De Bavay, as reflected in his early patents, was developing a process in which the surface tension of the liquid, without the extraneous aids of oil and acid, was the idea involved. The process works on the principle of the 'greased needle,' and there is none of the frothing which characterizes the Potter-Delprat, Minerals Separation, and Elmore processes. During the operation of the process there is simply a film of sulphides floating just as indicated in Fig. 10, Chapter IV. De Bavay, in the course of the development of his process, recognized the value of oil and acid as accelerating factors in surface-tension processes, and now uses oil for the same purpose as the others. The similarity in many ways of the early De Bavay patents to that of Bradford is apparent.

The first plant was erected on the mine of the North Broken Hill Mining company. This plant was altered and re-modelled many times while the process was being developed, and no complete story of these will probably ever be written, nor is it necessary. The plant did much good work all through the period of development from 1905 to 1908, when a measure of finality was reached in the methods. The process, as worked here in the later stages, is as follows: The tailing from the lead mill is first de-slimed, leaving practically a clean sandy product. The slime is discarded. The clean sand, crushed to about 40-mesh, is then fed into a mixing device, known locally as the A.Z. agitator, and mixed with cold acid solution of 0.19 strength. A photograph of the machine is shown in Fig. 28. This agitator is provided with a central tube worked with a rack and pinion for raising and lowering the upper end of the tube. The proportion of acid solution added is four or five

of solution to one of material. Thorough agitation is imparted to the mixture for a considerable time. The agitator is run at high speed for the purpose, as explained by the millman, of cleaning the surfaces of the mineral particles. This operation being completed, the speed of the agitator is reduced and the centre tube lowered so as to draw off the bulk of the solution, upon which is floating some metallic scum. When the excess of the solution has been removed, the centre tube is raised, clean wash-water added, and agitation renewed at high speed. After thorough washing, the speed of the agitator is again reduced, the excess of liquor removed

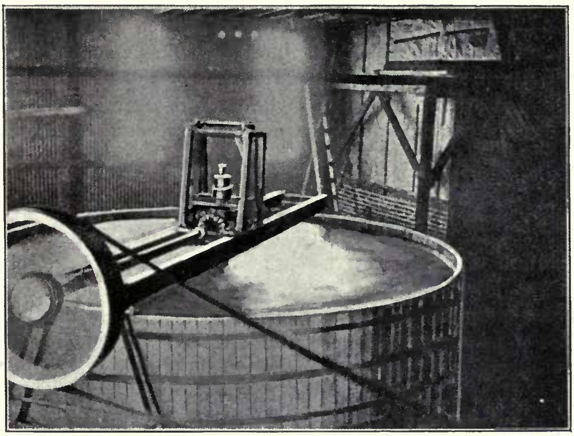
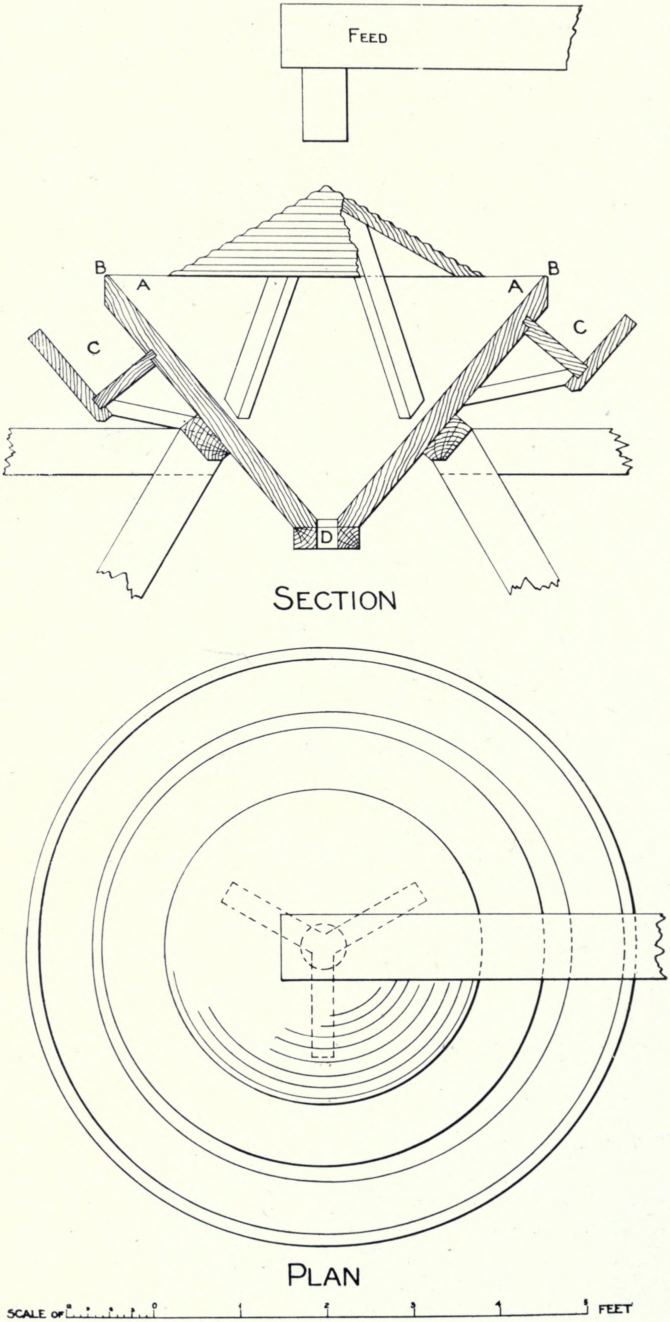


FIG. 28.—A.Z. Agitator.

as before, and a second washing effected to free the tailing of any acidity remaining. The scum of metallic particles drawn off is treated on vanners for the recovery of lead concentrate. The cleaned tailing is next conveyed to the 'oiling' vat. In this vat, which is provided with an agitator, the material is mixed with water, to which a definite proportion of oil has been added, and the whole mass thoroughly agitated to bring the metallic particles into contact with the oil. The oil is composed of one part of castor oil and four parts of low-grade kerosene; two to three pounds of oil to one ton of ore is used, and also some chlorine gas. From this oil-mixer the oiled pulp is elevated by means of a montejus and compressed air to the first tier of eighty-eight flotation cones, one of which is shown in section in Fig. 29, and in plan in Fig. 30 The material is fed to the cone at the top, and runs down over a series



FIGS. 29 & 30.—De Bavay Flotation Cone.

of corrugations to the water level A, where the sulphides float at the surface of the water (Fig. 30), and pass over the lip B into the launder C. The tailing, on the other hand, sinks through the surface of the water at B, and passes down the box and out at D. It is then fed to another similar cone and box with some further recovery of sulphides, and so on to a third and fourth cone and box. Throughout this manipulation, including the acid washing, the oiling, the raising with compressed air, and the flowing over the corrugated cone, the sulphide particles are repeatedly aerated, and as a result, especially after the oiling, take up their adhesive air films and float at B in exactly the manner shown in Fig. 2, Chapter IV. The function of the chlorine may be that of gasification of the sulphide particles, or, through the formation of hydrochloric acid, it might indirectly assist by acidulating the solution; or it may have some other obscure and secondary uses. The subjecting of the oiled pulp to compressed air may be an essential part of the operation. If so, the analogy to other oil-and-gas processes is close.

North Mine Plant.—The De Bavay plant on this mine was erected in 1905, and began operation in 1906. The first unit was estimated to treat 10 tons per day, and this was increased during the latter year until the plant was treating 300 tons per week. During 1907 more or less experimental work was done, and by the close of the year £65,000 had been expended on the plant. It was then considered capable of treating 1,700 tons per week, and during the year 17,000 tons of tailing was treated. In 1908 the capacity of the plant was further augmented, and a total of 74,200 tons was treated during the year. The 22,590 tons of concentrate produced this year averaged 47.5% zinc, 7% lead, and 6oz. silver per ton. This was the best concentrate produced by any flotation process at Broken Hill, and in this regard the De Bavay process continues to hold the lead. This factor is due to the careful de-sliming of the material before treatment. In 1909, 30,000 tons of concentrate was produced, assaying 48.5% zinc, 6.4% lead, and 5.9oz. silver. This high-grade concentrate was a noteworthy product. During the first half of 1910 the plant continued operations, but in August of that year it was closed because of the new phase of operations under the ownership of the Amalgamated Zinc, Ltd.

Amalgamated Zinc. — This company took over the Australian rights to the De Bavay process, the mill on the North

mine, and all the tailing contracts of the De Bavay Treatment Company. It purchased further dumps, and in 1909 began the construction of a large new mill at the extreme north end of the Broken Hill district. The first section of the new mill was started in March, 1910; the second section in August, and the third in October. The capacity of the whole plant is 1,800 tons per day. A re-treatment plant, consisting of tables, was installed, and the whole or a part of the flotation concentrate is treated thereby for the recovery of lead concentrate.

The tailings which are available for treatment by this plant are as follows: From the South mine 150,000 tons from the dump, and the current production of the lead-concentrating mill for ten years, a total of 1,750,000 tons, assaying 19% zinc, 3.5% lead, and 3.5oz. silver. This material contains 5 to 6% of carbonates, and gave the other processes which tried to treat it no end of trouble. From the North mine 100,000 tons of dump tailing, and the current production for ten years, a total of 1,700,000 tons, assaying 18.5% zinc, 4% lead, and 5oz. silver. From the Block 10 mine 370,000 tons of dump tailing, assaying 18.7% zinc, 4.8% lead, and 8.7oz. silver. In comparing this plant and process with others it should be kept in mind that this material is the cream of the district. It is of high grade, and free from slime, and for this reason is the most easily treated of any zinkiferous material now being treated.

Owing to the small capacity of each of the cone units, this plant covers a large area. The cost of the plant exceeds, per unit of tonnage, that of any of the other flotation plants, being £200,000, or £111 per ton daily capacity. Some auxiliary works were included in these figures, such as sulphuric acid plant, but it is certain that the De Bavay plant proper cost in excess of £100 per ton daily capacity for a plant of 1,800 tons per day.

RECOVERY.

If one of the best month's operations is taken and the content of the material treated is calculated from the figures given in the prospectuses and Government reports and from what is known otherwise of the district, the recovery in the De Bavay process works out as given in the following tables. We are, however, in the dark as to how much material was discarded as slime, which generally is considerably richer than the original material:

		ASSAY			CONTENT		
	Tons	Zn %	Pb %	Ag Oz	Zn Tons	Pb Tons	Ag Oz
Feed	41,430	18.8	4.0	5.0	7,789	1,657	207,150
Zinc concentrate	12,108	48.6	7.2	10.3	5,885	872	124,712
Lead concentrate	216	15.3	54.0	33.6	33	117	7,258
Total concentrate	12,324				5,918	989	131,970
Tailing	29,106	6.4	2.3	2.6	1,871	668	75,180

	Zn. %	Pb. %	Ag. %
Recovery in zinc concentrate ..	75.6	52.6	60.2
,, lead ,,	0.42	7.1	3.5
Total recovery	76.02	59.7	63.7
Ratio of feed to zinc concentrate	3.4 to 1		
,, ,, lead concentrate	191.8 to 1		
,, ,, total concentrate	3.36 to 1		

The following table gives the tonnage treated in this plant to 1912, with the products :

		ZINC CONCENTRATE				LEAD CONCENTRATE			
YEAR	FEED Tons	Tons	Zn %	Pb %	Ag Oz	Tons	Zn %	Pb %	Ag Oz
1910	252,725	74,925	48.1	6.9	7.9	1,243	11.7	57.5	24.7
1911	483,942	141,983	48.4	6.7	9.4	2,389	14.2	54.4	32.2
1912 6 mos.	259,452	70,496	49.2	6.3	9.3	984	16.6	53.8	35.7

CHAPTER VIII.

The Elmore Vacuum Flotation Process.

If water taken from an open vessel where it has been exposed to the air at ordinary temperature and pressure be confined in a glass vessel and subjected to a nearly complete vacuum, it will at once be evident that the water contained a gas in solution, because, as the vacuum increases, the gas—which in this case is air—will be seen forming in minute bubbles on the walls of the vessel, or at any other available points. At sea level and at ordinary temperature the quantity of air which open water holds in solution amounts to about 2.2% of its volume. This solution of air is explained by the law of Henry and Dalton. The amount of a gas which will go into solution in a liquid varies in general directly as the pressure and inversely as the temperature.

If we subject a pulp of acidified water and crushed ore to an operation whereby a small amount of oil has been applied to the sulphide particles in a suitable mixing vessel, and then subject this oiled, acidified pulp to a vacuum, the air in solution in the water is at once released, and attaches itself to the convenient points and angles of the oiled sulphide particles in the form of small bubbles, which gradually increase in size until they are sufficiently large to overcome by their buoyancy the force of gravity acting on the sulphide particles. When of sufficient size for this purpose the bubbles rise to the surface of the pulp, carrying along with them the sulphide particles; at the surface a froth, composed of air bubbles and mineral, forms, and is removed over a lip.

Francis E. Elmore invented an apparatus in which this operation is performed. This apparatus is unique in its features, and it is allowable to marvel at the ingenuity displayed in its invention.

The apparatus is shown in the accompanying sketch, Fig. 31. The pulp from the crushing mill flows continuously into the mixer A, into which also is introduced small quantities of oil, and, if required, of acid also, at the point B. The agitation is done by the rotation of the beaters C. The agitated pulp flows con-

tinuously from the mixer into the funnel D. The concentrate discharge-pipe E and the tailing discharge-pipe F are both sealed with water in the tanks G and H respectively. The upper end of the feed-pipe D enters the centre of the conical separating vessel I. Upon the application of a vacuum through pipe J, the pulp from the mixer is caused to ascend the feed-pipe and fill the conical chamber I. The rate of flow of the pulp down the pipe F being slightly less than that up the feed-pipe D, a small amount of the liquid overflows the lip of the annular space K, this quantity of

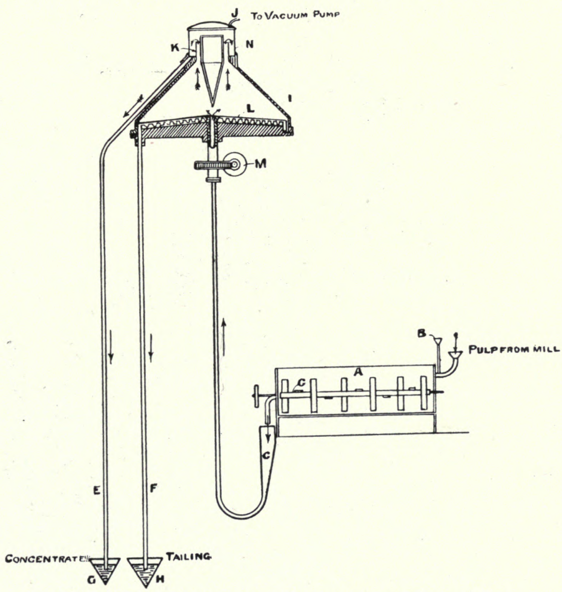


FIG. 31.—Diagram of Elmore Vacuum Machine.

liquid being sufficient to carry floating sulphides down the pipe E into the tank G. The rakes L are caused to rotate slowly by means of the worm and wheel M, the angle of the rake-blades being such as to cause the water-wetted gangue in the pulp to travel from the centre to the periphery of the conical chamber, whence the gangue continuously discharges down the pipe F. The feed-pipe D is usually about 25 to 30 ft. long, the tailing and the concentrate pipes E and F being a few feet longer, so that in effect the feed-pipe and tailing-pipe form the long and the short leg of a syphon; thus the power is supplied by the falling column of pulp in the tailing-pipe. So long as a continuous

flow of pulp is supplied to the mixer, a continuous and entirely automatic discharge of tailing and concentrate is secured. The annular space K is surrounded by a thick glass cylinder, or by a metal cylinder with one or more thick glass windows, through which the discharge of the sulphides over the lip of the annular ring may be observed.

Fig. 32 is a photograph of the separating vessel I. The capacity

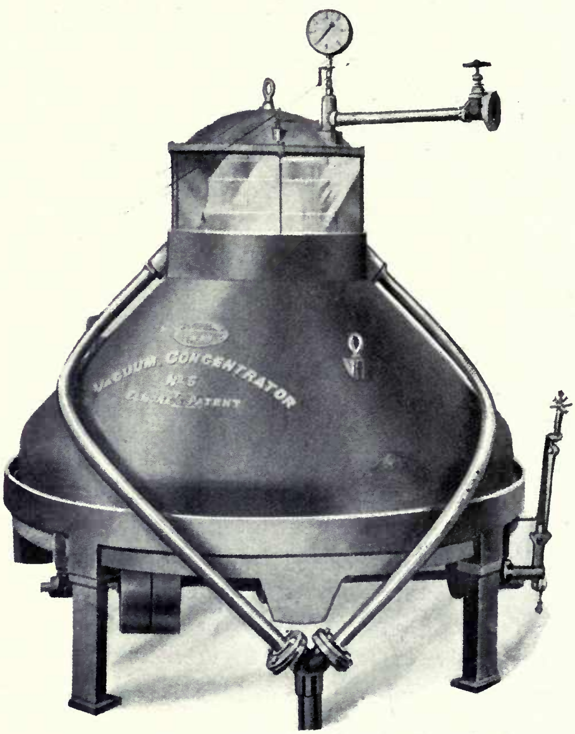


FIG. 32.—Elmore Vacuum Machine.

of each unit is from 30 to 50 tons per day, depending on the nature of the ore. The apparatus is constructed of metal, with the exception of the glass windows, and the mixer is a simple wooden trough with wooden beaters. The power required for a 5-ft. unit is said to be 2 to $2\frac{1}{2}$ h.p., including that required for driving the vacuum pump, mixer, and separator. The apparatus is usually constructed in standard units, the conical separating chamber of which is 5 ft. diameter. Including the mixer, conical separating chamber,

vacuum pump, all piping, etc., complete, the unit costs, f.o.b. London, approximately £350. The capacity of the apparatus naturally varies with the kind of ore to be treated, the fineness to which the ore has to be ground, and other conditions ; but a 5-ft. machine will ordinarily treat from 25 to 45 tons of crude ore per 24 hours.

The cost of the plant is low for so large a capacity. No expensive foundations are required, because the beaters in the mixing cylinder only make 30 to 40 r.p.m., and the rakes in the conical separating chamber only one to two revolutions per minute. Vibration is, therefore, entirely absent. No sizing of the pulp is required, and the operation of the plant is entirely automatic.

The quantity of oil and acid required is not the same for all ores, but usually amounts to not more than a few pounds, say from 3 to 10 lb. per ton of ore treated. A large variety of oils and similar substances have been tried and found suitable : Californian crude oil, Texas crude oil, Texas residuum, fuel oil, Russian crude, Borneo, Sumatra and similar cheap oils, tars, blast-furnace oils, olive-oil residues, oleic acid, kerosene, a variety of light oils, and fish oils.

WORKING COST.

The working cost must vary with the locality and the cost of supplies and labour. For the flotation-concentration at Broken Hill, exclusive of crushing, sizing, and any after-treatment of the concentrate, the working cost has been given as, roughly, 3s. per ton. As these figures were derived from a plant where sulphuric acid was comparatively cheap, it would be safe to take a round figure of four shillings per ton. In detail the figures referred to are as follow :

MEN EMPLOYED FOR SIXTEEN MACHINES.

Vacuum floor	1
Mixer floor	1
Discharging floor	1

Three shifts per 24 hours.

	s.	d.
Cost in grinding section ..	1	3.96
,, flotation section ..	2	4.16
,, drying section	1	3.64
,, re-treatment section ..		7.48
Royalty	1	0
	6	7.06

THE AMOUNT OF AIR.

If the pulp was made up in the ratio of 4 tons of water to 1 ton of ore, and if the ore was of the Broken Hill type, this would be 4 tons of water to about half a ton of sulphides. The water contains 2.2% by volume of air in solution, and it may be assumed that the vacuum releases 2% by volume. Four tons of water is 142 cubic feet; 2% of this is 3 cubic feet of air released for the purpose of floating half a ton of sulphides. Three cubic feet of air loaded with sulphides to an extent just sufficient to remain in suspension would require 3 by 63 lb. of sulphides = 189 lb. of sulphides, or considerably less than half a ton. There is enough air in a pulp of 1 ton of water to 1 ton of ore to lift 60 lb. of concentrate. The following table gives the amounts of air for pulps of different proportions:

Proportion water to ore.	Cubic feet of air available in this water.	Lb. of sulphide this will float.	Percentage of mineral in ore.
1 to 1	·75	60	2.7
2 ,, 1	1.50	120	5.4
3 ,, 1	2.25	180	8.1
4 ,, 1	3.00	240	10.8
5 ,, 1	3.75	300	13.5
6 ,, 1	4.50	360	16.2
7 ,, 1	5.25	420	18.9
8 ,, 1	6.00	480	21.6
9 ,, 1	6.75	540	24.3
10 ,, 1	7.50	600	27.0

As the proportion of water to ore rarely exceeds 6 to 1, and as the ores treated generally yield more than 16% of concentrate, it will be seen that some gas other than that naturally dissolved in the water must be found to effect flotation. This is generally secured by adding limestone to the ore, and then acid at the point where the pulp enters the vacuum chamber. It would be interesting to investigate whether, by limiting the quantity of gas available for froth production, it would be possible to secure differential flotation between lead and zinc sulphides. This machine seems especially adapted to the development of this idea.

APPLICATION OF THE PROCESS.

A large number of trials, both on a small scale and with a full-sized apparatus, have been conducted on a great variety of

ores, but it is not claimed that the process and plant are applicable to all ores, although its scope of application is wide.

The process has been applied with success to the concentration of ores which, because of their peculiar characteristics, are quite impossible of concentration by usual methods. For instance, chalcopyrite is readily separated from magnetite and spathic iron gangue; galena and zinc blende from a gangue of barite; and copper sulphides from oxide of tin, leaving the tin in the tailing to be subsequently separated by the usual methods. Zinc, copper, and lead minerals may be separated from garnet and similar heavy gangue; and such minerals as antimony or molybdenum sulphides which, because of their friable nature, suffer prohibitive losses in water concentration, are found amenable to treatment by the Elmore process. Cinnabar and iron pyrite carrying gold are readily concentrated, yielding high-grade products with practically clean tailing. The native metals, gold, silver, and copper, when in a fine state of division, are said to concentrate readily and with very small loss.

Continuous working has shown that the plant is eminently practical; no delicate adjustments are required, wear and tear is to all intents a negligible quantity, and the excellent mechanical design and substantial construction of the apparatus have made breakages almost unknown.

DOLCOATH, CORNWALL.*—In certain parts of this mine the ordinary tin ore of Cornwall is found impregnated with varying proportions of sulphides, principally of copper. This ore is crushed in an Edgar Allen ball-mill, and passed direct to one Elmore vacuum unit. By this operation almost the whole of the sulphides are recovered as a high-grade copper concentrate, which is saleable as such. This concentrate contains a remarkably small proportion of tin, on the average probably not exceeding 2 to 3 lb. of tin per ton of concentrate. Substantially, the whole of the tin oxide is left in the tailing from the vacuum unit. The tailing is subsequently treated by Frue vanners, etc., in the ordinary way for the recovery of the tin oxide. The oil and acid used in no way injuriously affect the subsequent recovery of the tin. This plant was supplied to the Dolcoath company in March, 1907, and yielded highly satisfactory results for some time, giving an

*_Engineering & Mining Journal_, December 14, 1907, by Edward Walker.

extraction of over 90% of the copper contents, but the plant is not now in use.

RAMSLEY MINE, DEVONSHIRE.—Here the ore consists of a mixture of chalcopyrite and bornite with some chalcocite in a slaty micaceous gangue. The average grade of the crude ore is about 2½% copper. It is crushed in stone-breakers, high-speed rolls, and a Huntington mill in the usual way, the pulp being sent direct to one unit of Elmore plant. On the average the concentrate produced assays about 12% copper.

DOLGELLY MINE, NORTH WALES.—The ore consists of chalcopyrite with varying proportions of iron pyrite in a schistose gangue. The grade of the ore is usually about 1.2% copper, 0.08oz. gold, and 0.8oz. silver per ton. The ore is crushed by a reciprocating stone-breaker, followed by a 20-head Californian stamp-battery (1,050lb.), through 6-mesh screens. The pulp from the battery is sized on a 16-mesh screen, and the oversize re-crushed in a grinding pan. The pulp is then sent direct to 3 Elmore units, and yields a concentrate of about 12% copper, 0.7oz. gold, and 7oz. silver per ton, the tailing assaying about 0.25% copper, with very small amounts of gold and silver. Prior to the installation of the vacuum plant, much money had been spent at this mine on various forms of water-concentration machines; but, owing to the extreme softness of the copper mineral and the unusually tough character of the rock, the loss of fine material was always prohibitive.

ZINC CORPORATION.*—The material treated here was a zinc tailing from the lead-concentration plants. The gangue consists largely of quartz, garnet, and rhodonite, being of practically the same specific gravity as the blende with which it is associated; hence no separation by ordinary water-concentration was possible. Much of the tailing on the dump was already fine enough for direct treatment in the Elmore plant; that portion that was too coarse was crushed in 12 grinding pans, sized on improved revolving screens, the oversize being re-crushed in six additional grinding pans. The average assay of the material treated in this plant was about 19% zinc, 5% lead, and 8oz. silver per ton. This yielded a concentrate assaying on the average about 43% zinc, 11% lead, and 17oz. silver per ton. It was found that, if this concentrate was dried and subjected to a sufficiently high tempera-

*_The Mining Journal_, February 20, 1909, by A. Stanley Elmore.

ture to expel the small quantity of oil which it contained, the de-oiled concentrate could then be mixed with water and passed over Wilfley tables, yielding a zinc product assaying 46% zinc, 6.1% lead, and 13oz. silver per ton, and a lead concentrate assaying about 57% lead, 16% zinc, and 37oz. silver per ton. The assay of the final residue depended, to a great extent, upon the more or less oxidized condition of the mineral, much of the material on these dumps having been exposed to atmospheric oxidation for many years; but the following may be taken as fairly representative: Zinc, 5.90%; lead, 2.5%; and silver, 4oz. per ton.

Fig. 33 gives a condensed flow-sheet of the arrangement of this mill, including crushing, sizing, flotation, and re-treatment on Wilfley tables. The plant contained 16 units, and was installed only after exhaustive trials had been conducted with one unit. The mill was in continuous operation for two years, and gave a higher capacity, better grade of concentrate, and greater percentage of extraction than was indicated by the trials with the one-unit plant.

The following table gives the total tonnage treated from the beginning of February, 1908, to the end of July, 1911, inclusive, with the results:

FEED		Tons	714,399
	Assay	Per cent. Zn	19.1
		oz. Ag	7.9
		Per cent. Pb	5.5
FINAL ZINC CONCENTRATE		Tons	241,710
	Assay	Per cent. Zn	46.0
		oz. Ag	13.34
		Per cent. Pb	6.63
FINAL LEAD CONCENTRATE		Tons	20,639
	Assay	Per cent. Zn	15.84
		oz. Ag	36.76
		Per cent. Pb	56.57
ZINC SLIME		Tons	7,977
	Assay	Per cent. Zn	38.85
		oz. Ag	21.11
		Per cent. Pb	13.55
RESIDUE		Tons	452,050
	Assay	Per cent. Zn	4.88
		oz. Ag	3.67
		Per cent. Pb	2.59

PERCENTAGE DISTRIBUTION.

FEED	Per cent.	.. ..	100
FINAL ZINC CONCENTRATE ..	Per cent. Weight	..	33.8
	,, Zn ..	..	81.4
	,, Ag ..	..	57.1
	,, Pb ..	..	40.6
FINAL LEAD CONCENTRATE ..	Per cent. Weight	..	2.9
	,, Zn ..	..	2.4
	,, Ag ..	..	13.4
	,, Pb ..	..	29.6
TOTAL CONCENTRATE ..	Per cent. Weight	..	36.7
	,, Zn ..	..	83.8
	,, Ag ..	..	70.5
	,, Pb ..	..	70.2
RESIDUE	Per cent. Weight	..	63.3
	,, Zn ..	..	16.2
	,, Ag ..	..	29.5
	,, Pb ..	..	29.8

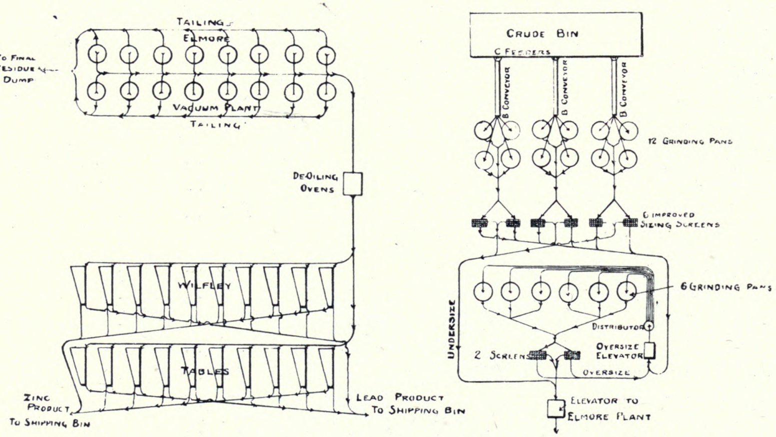


FIG. 33.—Flow-Sheet of Elmore Plant.

The Elmore process has now been discarded for reasons before given, and the Minerals Separation process installed in its place.

EDMUNDIAN COPPER MINE.—The ore at this mine in South Africa consists of chalcopyrite finely disseminated through a felspathic gangue. It is crushed by stone-breakers and Holman pneumatic stamps, and passes direct to a two-unit Elmore plant. The ore assays on the average about 2.5%, and yields a concentrate assaying about 22.5%, with a recovery of 85%.

Garpensberg Mine, Sweden.—The ore consists of a quartzitic gangue with some magnetite carrying chalcopyrite and iron pyrite. The ore, although fairly heavily mineralized with iron pyrite, is of low grade, assaying on the average about 1% copper. The crushing plant consists of a stone-breaker, followed by rolls, the product going to jigs and tables in the ordinary way. The fine tailing, together with the jig tailing after re-crushing in wet ball-mills, is treated in the vacuum machines. One unit of plant was tried first ; later two more were installed, but the plant is now closed.

Traag Mine, Norway.—The ore carries both zinc and lead associated with a heavy gangue. After crushing in stone-breakers and in an Allis-Chalmers Anaconda-type Huntington mill, the pulp is treated on Wilfley tables for the production of a lead concentrate. The tailing from the Wilfley table is passed to a one-unit Elmore plant, which yields a concentrate assaying on the average 58% zinc. The zinc sulphide in the ore is present in the form of a very friable resin blende, and, in consequence of excessive sliming, coupled with heavy gangue, could not be collected by any ordinary water concentration appliances. This plant has now ceased working.

Hadeland Mine, Norway.—The ore consists of blende associated with a large proportion of magnetite and some spathic iron. Trials with various water-concentration appliances had all proved unsatisfactory. The ore is crushed in Krupp ball-mills, and sent direct to the Elmore plant. It yields a high-grade concentrate with a satisfactory extraction. The company, after having operated the one-unit plant for about six months, has ordered additional units.

Telemarken Mine, Norway.—The ore consists of chalcopyrite and bornite in a gangue composed of hornblende, micaceous schist, and hard quartz. The crude ore from the mine is hand-sorted with a view to rejecting some of the waste. The ore thus enriched assays on the average about 4.5% copper. It is crushed in a No. 5 Gates crusher, followed by Ferraris wet ball-mills. The pulp is sent direct to a three-unit Elmore plant, from which a concentrate assaying about 26% copper is obtained, the final tailing containing only 0.20%, thus giving a recovery of about 95% of the total content. Fig. 34 shows a section of the vacuum plant, and Fig. 35 a flow-sheet of the plant at this mine.

Sulitelma Mine, Norway.—The ore carries copper in the

form of chalcopyrite associated with a large proportion of iron pyrite, the gangue being micaceous schist. As the ore comes from the mine it is crushed in large stone-breakers, and carefully hand-sorted with a view to selecting clean lump pyrite, which is sold to sulphuric acid works for its sulphur content, the burnt ore

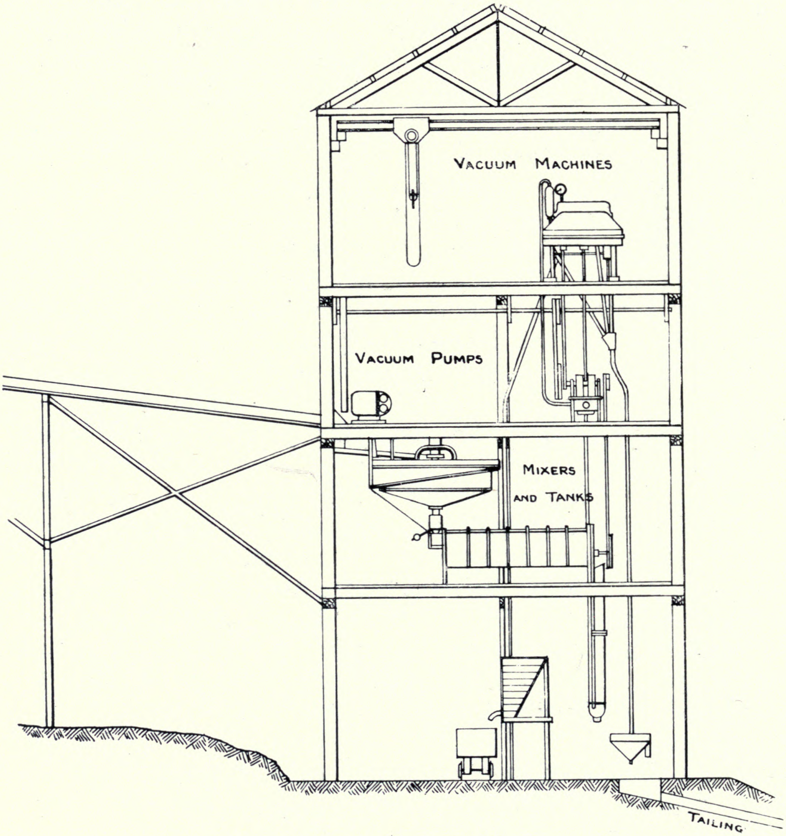
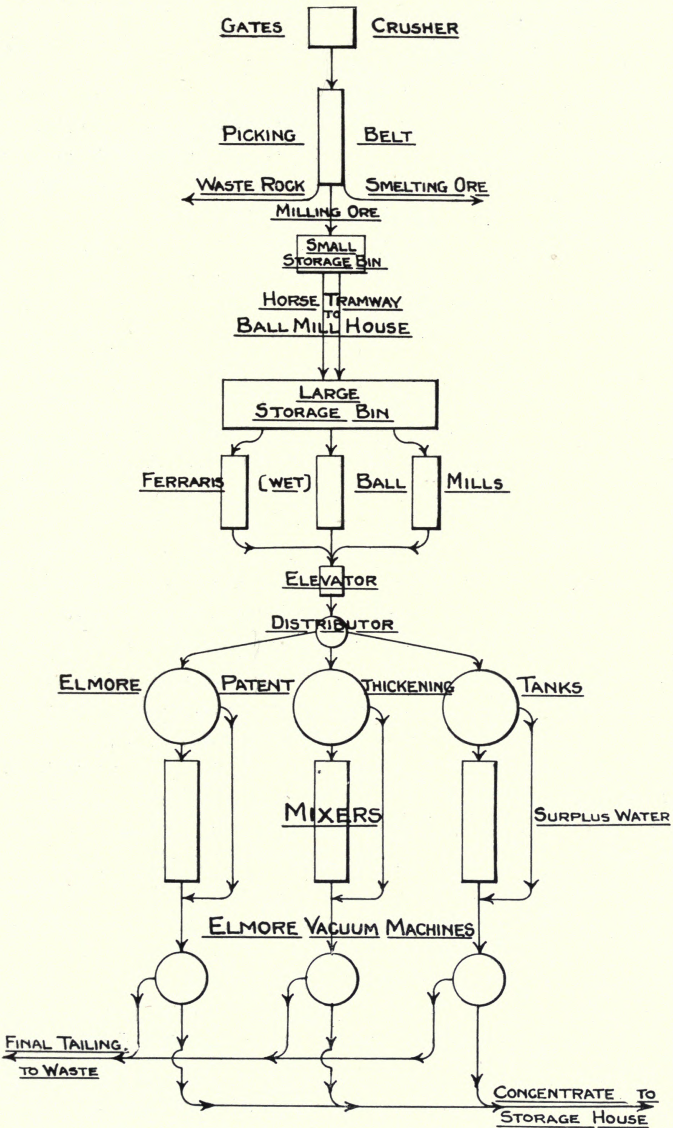


FIG. 34.—Section of Elmore Plant.

being subsequently treated for its copper content. The low-grade ore left after hand-sorting is crushed in rolls and passed to jigs, tables, and vanners. This water-concentration plant is of first-class design, operated with good labour and under excellent technical supervision and control. Nevertheless, the loss of copper in the tailing is heavy owing to the friable nature of the copper pyrite. The residue from this water-concentration plant



FLOW SHEET
TELEMARKEN MINE, NORWAY.

FIG. 35.

varies in grade from 1 to $1\frac{1}{4}\%$ copper, with a quite considerable proportion of iron pyrite and some magnetite. The concentration mill handles about 800 to 900 tons a day, and produces about 500 to 600 tons a day of tailing. This tailing is in the form of an unusually dilute pulp, the proportion of water to solid being probably 100 to 1. At the present time about 400 tons of solid per day with the above proportion of water is sent to the 12-unit Elmore plant for the recovery of the copper mineral. Arrangements are being made which will enable the whole of the 500 to 600 tons of tailing from the water-concentration plant to be sent to the Elmore plant. The small part of the tailing, which is too coarse for treatment direct in the Elmore process, is re-crushed by Heberle ball-mills. The pulp, which, as before stated, is associated with an immense amount of water, is run into large settling-tanks with a view to getting rid of the excess of water before treatment in the Elmore plant. Concentrate varying from 6% up to 11% of copper (the grade depending upon the proportion of iron pyrite) is produced. The final tailing assays on the average 0.2% copper. The great bulk of the material handled by the vacuum machines consists of absolute slime. An average of about 250 tons of concentrate per week is produced from waste material which had previously been discharged direct to the tailing dump. Six additional machines have been delivered to this firm, and will shortly be erected at one of their other mines.

Saxberget Mine, Sweden.—The ore here is a mixed zinc-lead-silver material, which, after crushing in stone-breakers and wet Grondal ball-mills, is treated on tables for the recovery of the lead. The lead recovery, however, is not good, and consequently the tailing from the tables contain notable proportions of lead and silver in addition to the zinc. Various attempts had been made previously to treat the tailing without success. The Elmore plant produced a mixed lead-zinc-silver concentrate, which was subsequently smelted in an electrical furnace. Its use has been discontinued and a Minerals Separation plant of 125 tons per day capacity is at present in operation.

Other Elmore plants have been installed in several places, but data as to results are not available.

CHAPTER IX.

The Minerals Separation Process.

This process represents the joint efforts of Sulman, Picard, and Ballot, and various improvements in processes and apparatus have been added at different times by Froment, Cattermole, Sulman, Picard, Ballot, Higgins, Chapman, Lavers, Greenway, Nutter, Hoover, and others of a large staff. The owner of all these patents is the Minerals Separation, Ltd., a company, the special province of which was intended to be the development of flotation processes. The company licenses the use of the process.

The application of this process to a typical Broken Hill zinkiferous material will be described. This material is the tailing from the lead-concentrating mills after the major part of the lead has been removed by gravity-concentration. Mineralogically, the material has approximately the following composition :

	Per cent.
ZnS	27.1
$ZnSO_4$	2.4
PbS	6.4
$PbSO_4$	1.3
FeS_2	2.5
$MnCO_3$	4.6
$CaCO_3$	3.2
SiO_2	42.4
Total	89.9

The balance of the 100% is made up mostly of garnet and rhodonite and a complex carbonate containing iron, calcium, zinc, and magnesium. The blende is 'black jack' of about the following composition :

	Per cent.
ZnS	81
FeS_2	14
MnS	3

The average assay of the material to be treated by flotation is :

Zinc	14 to 20%
Lead	6%
Silver	7.5 oz. per long ton.

It is necessary to crush this material to about 40-mesh for three reasons : (1) Larger particles float with reluctance ; (2) the sulphides must be freed from the gangue ; (3) crushing has a brightening effect on the sulphide particles.

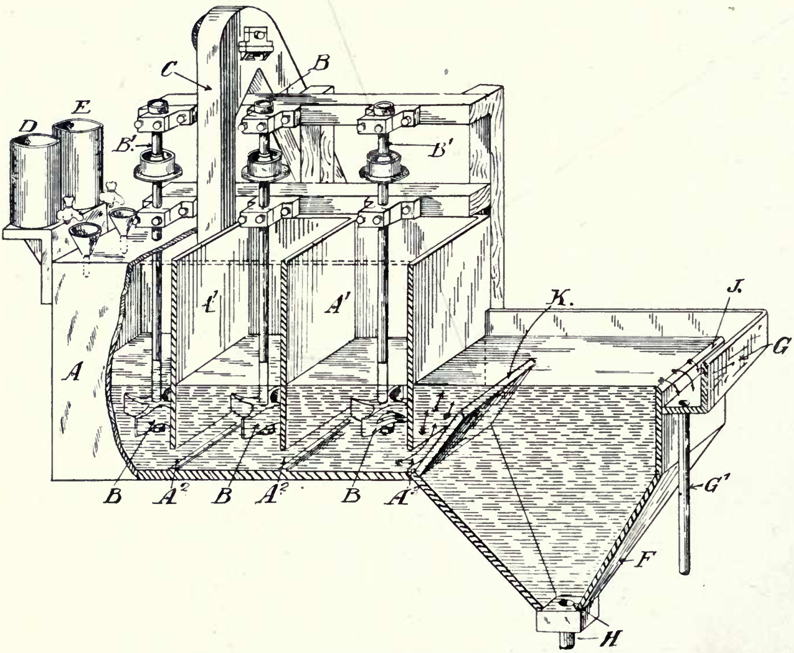


FIG. 36.—Hoover Frothing Machine.

In this process wide limits as to the amount of slime produced in crushing are permissible. A certain amount of slimed sulphides is absolutely essential to the best frothing result ; but there seems no upper limit beyond which fine crushing is deleterious. One plant worked successfully on material 95% of which would pass a 100-mesh screen. After the ore is crushed to the requisite fineness it is de-watered to a pulp as near as may be three of water to one of ore, this proportion having been determined by a series of trials extending over several years to be the most likely to produce good results under the other conditions imposed.

After de-watering, the pulp is run into an apparatus designed by the author, and patented for Minerals Separation, Ltd., owners of this process, in British Patent 4911 of 1909. The original form of the apparatus was as in Fig. 36, but several improvements were made later. In order to understand the later form it will be easiest to begin with a description of the original apparatus. This consisted essentially of three mixing and agitating compartments joined to a modified spitzkasten. The three mixing compartments were connected together by apertures A_2 at the bottom of the partitions A_1. These apertures can be of almost any shape as long as the area of the aperture is within certain wide limits. The right-hand mixing compartment is connected with the spitzkasten by the aperture A_3 similar in all respects to the aperture A_2. At J is a horizontal lip, which maintains a water-level, and at H is an outlet which is of such a size that there will always be an overflow over J. The agitators B are driven by belts or gears and should travel with a peripheral speed of about 1,200 or 1,300 feet per minute. This will cause the liquid pulp in the compartments to line the sides of the compartment about half-way to the top, and at the centre of the compartment the water-level will be considerably lower than it is in the spitzkasten. Fig. 37 is a longitudinal section of the three mixers and spitzkasten, and shows the position assumed by the water during operation. At K is a baffle over which the pulp must flow, the edge of K being a few inches below the water-level J, this distance depending on the size of the plant and other factors, the outside limits being 2 and 8 inches. At D is an apparatus for feeding acid, and at E is an apparatus for feeding oil.

The 3 to 1 pulp is fed into the compartment to the left of Fig. 36 at C, and along with it are fed in also, say, 2lb. of oil and 10lb. of sulphuric acid to the ton of ore. Live steam is also introduced into this compartment through a pipe (not shown) in sufficient quantity to raise the temperature of the pulp to 70° C. Owing to the speed of the agitator these ingredients are thoroughly mixed; in fact, they are churned violently. Large quantities of air are beaten into the pulp. By running the machine for a few minutes on water alone it will be observed that the quantity of air so beaten into the pulp is enormous, for the clean water will be milk-white. As the inflow of pulp is continuous, the outflow from the left-hand compartment into the middle compartment is also continuous and of equal volume. In the middle compartment

the pulp receives a further violent agitation, and then passes continuously into the right-hand compartment to be agitated once more. From the right-hand compartment the froth emerges through A_3 into the spitzkasten over the baffle K. The rate at which the pulp passes over the baffle K is exactly the same as that at which it is fed at C. As the pulp emerges from A_3 a dense froth, composed of sulphides and bubbles of gas, immediately rises to the surface, where it floats along to J, and passes over into the launder G, and so to the bins. The gangue, on the other hand,

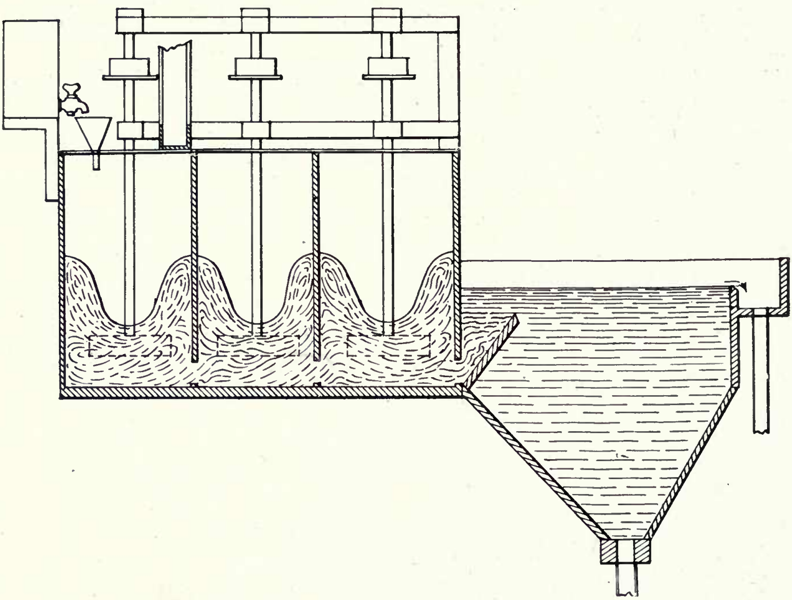


FIG. 37.—Diagram of Water Levels.

does not float, but just manages to get over the baffle K, and then drops to the tip of the spitzkasten, and is removed at H.

A single box of the above description will not give a perfect extraction, and it is necessary to give the pulp a second and third treatment in a similar box with less agitation. This can be done by simply building three sets like that shown in Fig. 36, and placing them one under the other as in Fig. 38. A set of boxes of this design, with mixing compartments 3 by 3 feet and a spitzkasten 4 by 5 ft., will treat 400 tons of this material per day, and will make something over 150 lb. of clean zinc concentrate per minute.

Instead of placing three sets of this kind one above the other, a much simpler mechanical arrangement can be made which saves

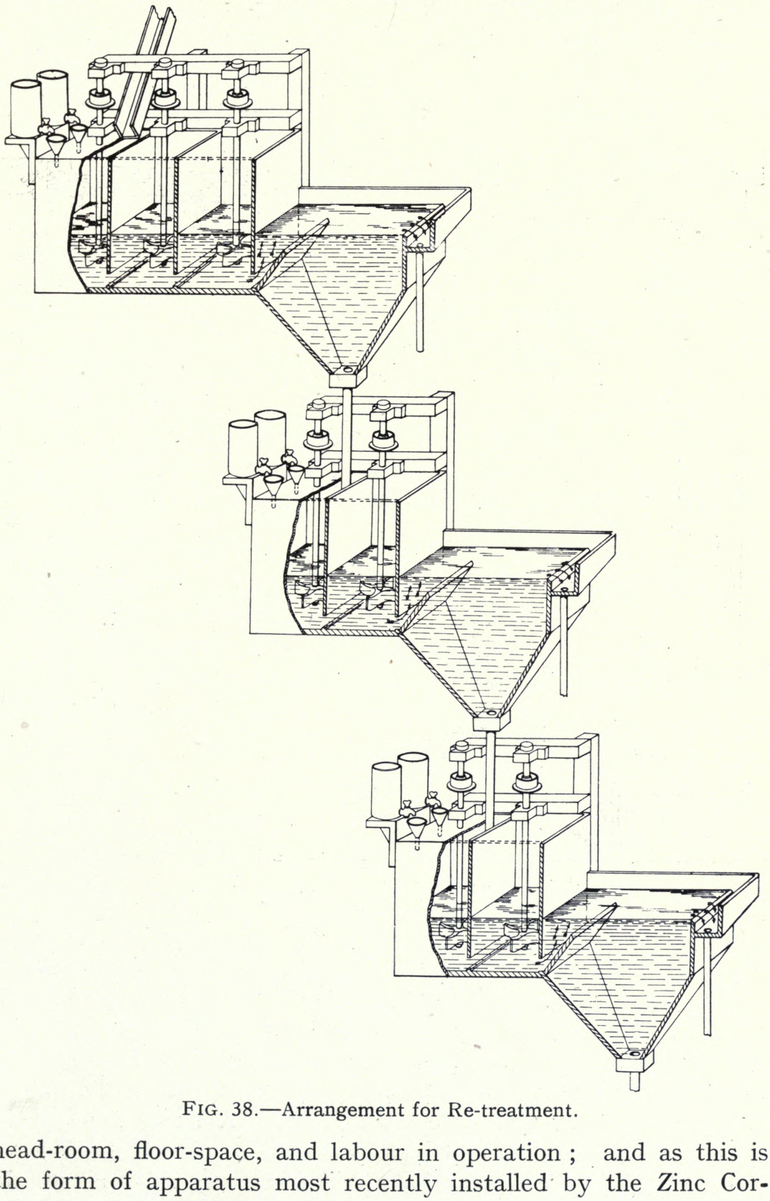
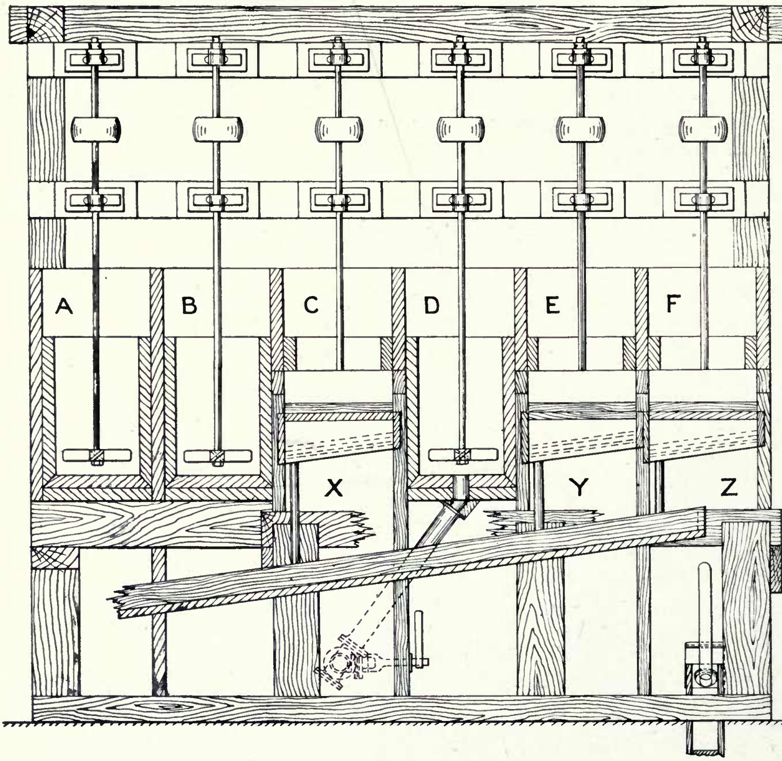


FIG. 38.—Arrangement for Re-treatment.

head-room, floor-space, and labour in operation; and as this is the form of apparatus most recently installed by the Zinc Cor-

poration, and represents the latest development in the process, it will be described at the risk of some repetition. These ideas were also patented for the Minerals Separation, Ltd.

This arrangement of plant makes use of the centrifugal effect of the agitators, and uses them partly as pumps. Referring to Figs. 39, 40, and 41, which are elevation, plan, and section of the

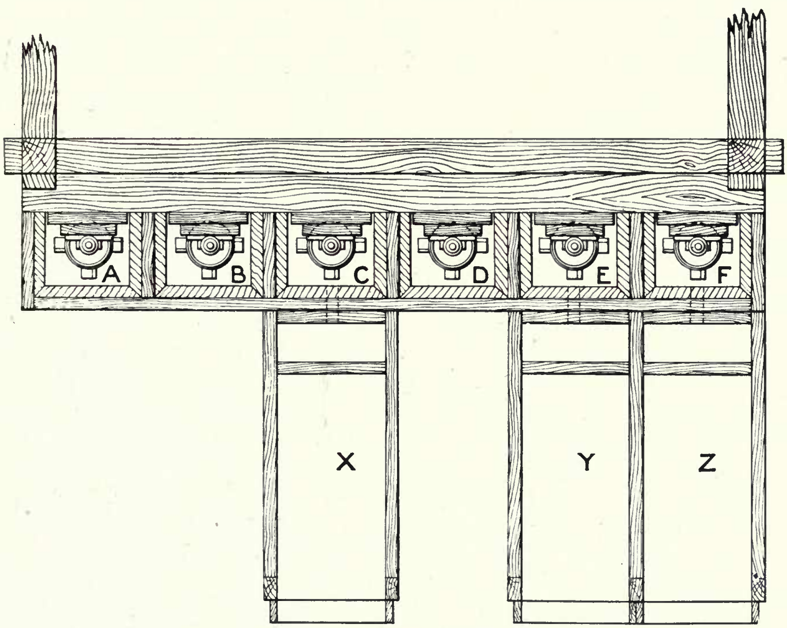


FRONT ELEVATION.

FIG. 39.—Hoover Single-Level Apparatus.

latest arrangement, A, B, C, D, E, and F are mixing compartments, each containing an agitator running at high speed; X, Y, and Z are spitzkastens. The ore, water, oil, acid, and steam are fed into the compartment A in proper proportions, where the pulp is thoroughly mixed and violently agitated; A has a hole at the bottom, which allows the pulp to pass into B, where there is more violent agitation; B has a hole in the bottom, which allows the

pulp to pass into C and from C goes over a baffle into the spitzkasten X, where a heavy, dense mineral froth is floated over the lip of X; the gangue, along with some of the sulphides, passes to the tip of the spitzkasten X, the tip being connected by a pipe M with the bottom of D. The agitator in compartment D acts as a centrifugal pump, and draws the material from the tip of X up into compartment D, where the pulp receives further agitation and aeration. The lift required of this pump is very



PLAN

FIG. 40.—Hoover Single-Level Apparatus.

slight, for it will be observed that there is one liquid level throughout the whole of this combined arrangement; the agitator pump in D has to pump against a head which is practically only the friction head of the system. From D the pulp passes to E, where further aeration by agitation is given; from E the pulp passes over a baffle into the spitzkasten Y, the froth flowing over the lip of Y and the gangue with a little remaining sulphide dropping down to the tip of Y; the tip of Y is connected by a pipe N with the bottom of the mixing compartment F, and the agitator in F acts

as a pump to draw the pulp up into F. Here the head on the pump is only the friction head, and as in the case of M, N is also the suction side of the centrifugal pump. The pulp gets further agitation in the mixing compartment F, and finally emerges over a baffle into the spitzkasten Z, where the last available

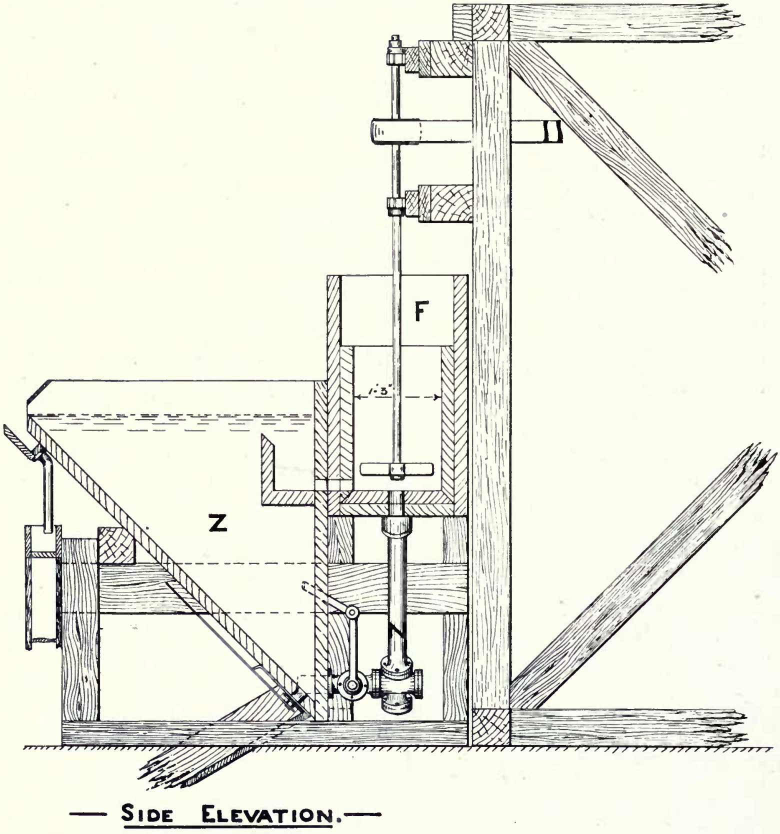


FIG. 41.—Hoover Single-Level Apparatus.

mineral froth passes over the lip, and the gangue drops down to the tip, from whence it is drawn through a regulated opening and passes to the tailing flume. A perspective drawing of this plant is also shown in Fig. 42, which may help to understand the scheme.

This plant has the merit of extreme compactness. One unit of 400 tons per day capacity would occupy a floor space of less

than 30 by 10ft., and less than 12ft. of vertical height. The whole operation is in front of one man, and the labour required is so reduced to a minimum. By placing two units front to front, one operator should watch the treatment of 1,000 tons per day. These agitators take 5 h.p. each for a plant of 400 tons per day capacity, and on most ores six agitators would be ample. Some ore would probably require that the agitators be arranged first a set of three followed by a spitzkasten ; then a set of two followed by a spitzkasten ; and lastly, one agitator followed by a spitzkasten. Other forms consist of one agitator for each of eight spitzkastens, and variations of connections in each case depending on the nature of the ore.

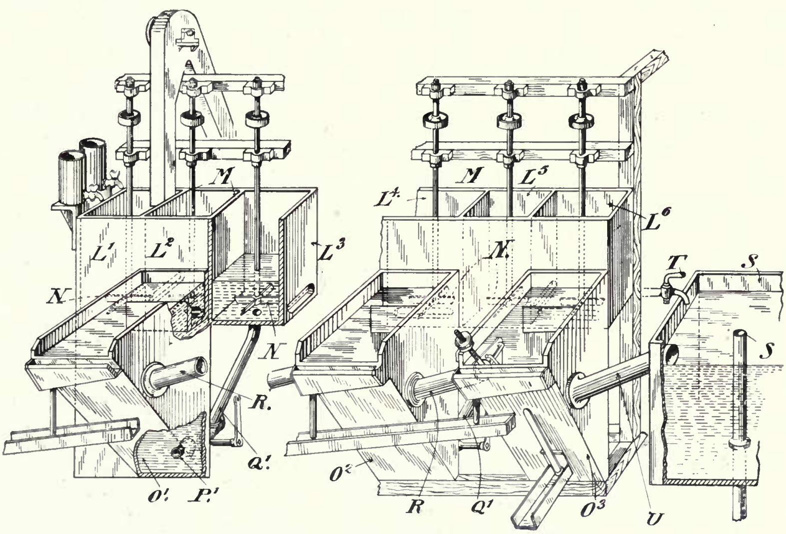


FIG. 42.—Hoover Single-Level Apparatus.

In most flotation plants, whether using this process or the others previously described, it will be found of decided advantage to use the water over and over again, as there is some latent acidity always in solution after the flotation is complete, and besides, the salts in solution have a beneficial coagulating effect. If the salts in solution increase to beyond 4,000 grains per gallon, the millmen have acquired the idea that it has a detrimental effect on the flotation, but this does not seem to be based entirely on sound reasoning ; the detrimental effect is probably an indirect result of salts in solution, and could be obviated by proper manipulation.

One of the recent improvements in this process is by way of

using as a froth-producing agent a soluble substance to replace the insoluble oil formerly used. The soluble substances which are available for this purpose are: Alcohols, especially amyl alcohol and some of its soluble salts, such as amyl acetate; all the phenols and their near derivatives; the turpentines and many of the products from the destructive distillation of wood; most of the essential oils, and especially the oil from *eucalyptus amygdalena*, one of the most common eucalyptus in Australia. This last is probably the best of all, and as the quantity used is less than a pound per ton of ore, the high price of the oil does not hinder its use. One decided advantage of using these soluble frothing agents is that where a subsequent treatment of the concentrate is desired for the separation of lead and zinc sulphides, it can be treated directly on tables. Where an insoluble oil was formerly used it was necessary to burn this insoluble oil, as it made the sulphides gummy, and they could scarcely be separated by gravity.

The following figures give the dimensions of units of various sizes. Part of this information has been derived from actual observation, and part is deduced from the known behaviour of the process under given conditions. No doubt further work with the process will modify the ideas as to size, even if the form is maintained as at present.:

Estimated daily capacity.		Tons. 50–60	Tons. 100	Tons. 200	Tons. 300	Tons. 500
Agitators	Number	6	6	6	6	6
Right and left	Diameter, inches ...	12	14	16	18	24
	Height of web, inches	2	2	2¼	2½	4
Agitator	Number	6	6	6	6	6
	Diameter, inches ...	1¼	1⅝	1¾	2	2¼
	r.p.m.	440	380	335	300	225
Mixing boxes	Number	6	6	6	6	6
	Width, inches ...	16	18	22	25	36
	Depth, inches ...	36	40	37	43½	54
Spitzkastens	Number	3	3	3	3	3
	Width, inches ...	16	18	22	25	36
	Depth, inches ...	51	58	62	62½	78
	Length, inches ...	39	42	45	48	54
Openings from Mixers to Spitzkastens	Number	3	3	3	3	3
		One into each spitzkasten.				
	Dimensions, sq. in. ...	18	25	32	36	48
	Height above floor of mixer, inches ...	2	2	2	2	2
Main driving-shaft	Number	1	1	1	1	1
	Diameter, inches ...	1½	2	2½	2½	2¾
	Speed	288	250	220	96	363
Driving-shaft pulleys	Number	6	6	6	6	6
	Diameter, inches ...	12	16	20	24	32
	Width, inches ...	4½	6	6½	9	11
Return pipes from Spitz to next mixer	Number	4	4	4	4	4
	Diameter, inches ...	2	2¼	3	3¼	4

A further improvement to this apparatus, that eliminates all pipes, pumps, and valves, and makes the process practically independent of the operator, is illustrated below. The apparatus and its application to flotation processes will be sufficiently clear from the following descriptions, and Figs. 43, 44, and 45, which are elevation, plan, and section of the new machine :

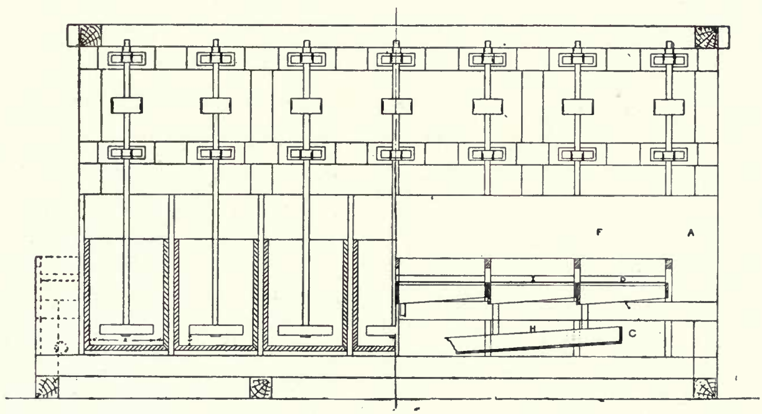


FIG. 43.—Elevation Hoover Valveless Apparatus.

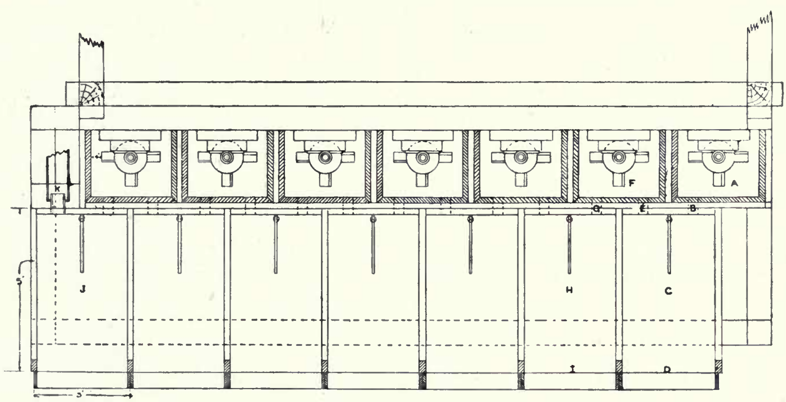


FIG. 44.—Plan Hoover Valveless Apparatus.

The ore is fed in at A (Figs. 44 and 45), along with water, oil, and acid, and after a period of agitation and mixing, emerges at the opening B into the flotation-box C. A portion of the sulphides floats and is removed at the lip D. The remainder of the sulphide with the gangue, etc., is drawn through the hole E

into the mixing-compartment F, whence, after further agitation, it is discharged from the hole G into the flotation-box H, where more floating sulphides are removed at the lip I, and so on through the whole series, alternately agitating and taking off a froth, until the last frothing-box J, where the gangue-sand fully depleted of sulphides is withdrawn at the valve K. The agitators in the mixing-compartments should run at a peripheral speed of about 1,500 linear feet per minute.

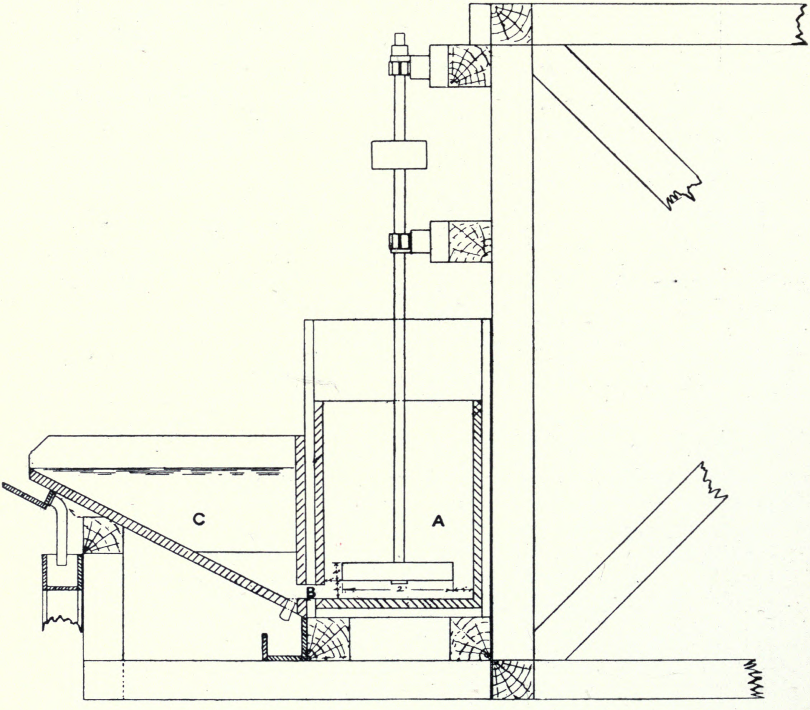


FIG. 45.—Section Hoover Valveless Apparatus.

Another form of apparatus which has many advantages of simplicity is shown in Figs. 46, 47, and 48. In this case the pulp moves in a straight line through the whole series, receiving successive agitations at A, A, A, and yielding froths at B, B, B, which froths are drawn off at the lips D, D, D. At C is a valve and pipe which regulate the outflow of the tailing and the height of water in the whole series. The agitators in the mixing-

compartments A, A, A should run at a peripheral speed of about 1,500 linear feet per minute. In B, B, B there are slow-moving agitators to keep the sand slowly in motion; these should run at 10 to 20 r.p.m., but not fast enough to break the surface of the water. On some ores the agitators may not be needed in B, B, B, etc.

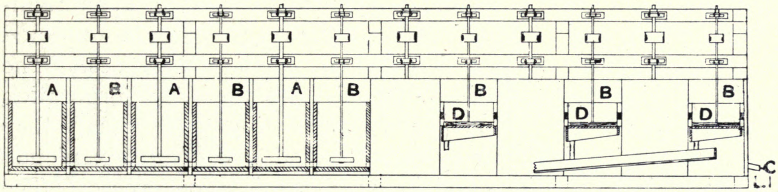


FIG. 46.—Elevation Hoover Valveless Apparatus.

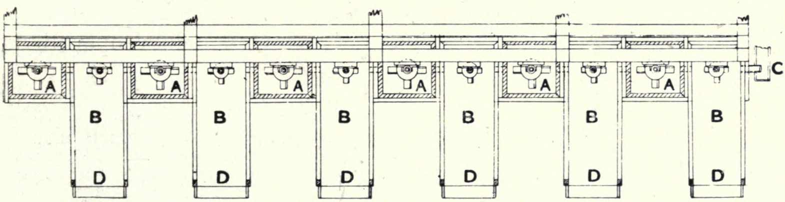


FIG. 47.—Plan Hoover Valveless Apparatus.

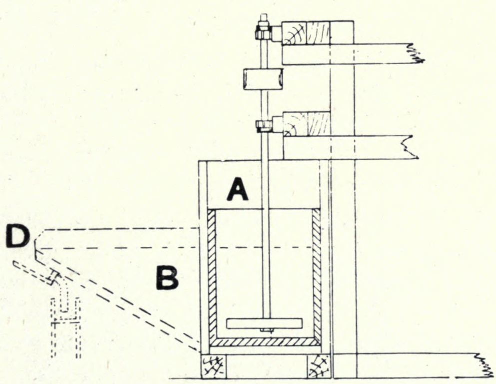


FIG. 48.—Section Hoover Valveless Apparatus.

OLD GRANULATION PLANT.

The first mention of the Minerals Separation process is in the Annual Report for the Department of Mines of New South Wales for 1904, where it is recorded that the Sulphide Corporation had

been experimenting with an oleaginous process, and that a plant would be erected in the following year. In 1905 the process was described as being either one where the mineral was coagulated and sunk, or where a small amount of oil was used to make the mineral float. At this plant the patents of the company had their first practical application. During 1905 the Cattermole idea was abandoned, and the plant was altered to a flotation-process plant, and operated as successfully as could be expected in a plant which had undergone so many vicissitudes. The work here in 1907 served as a model for the Zinc Corporation in their first trial of the Minerals Separation process, but they were not able to duplicate the results, and as a result abandoned the Minerals Separation, and installed the Elmore process. The plant continued operations during 1907, but was finally closed in 1908. The material treated was typical Broken Hill dump-tailing from the lead-concentrating mills, and the three years' operations are here shown.

	FEED				CONCENTRATE						
		ASSAY				ASSAY			RECOVERY		
YEAR	Tons	Zn %	Pb %	Ag Oz	Tons	Zn %	Pb %	Ag Oz	Zn %	Pb %	Ag %
1906	23,709	20.4	6.4	7.4	8,013	44.0	11.8	14.8	72.8	62.1	67.3
1907	65,705	21.0	5.6	7.0	20,621	45.2	9.7	13.4	67.7	54.2	60.7
1908	46,394	20.4	5.6	7.0	16,513	45.1	9.5	13.8	78.7	60.0	69.6

This plant at periods gave much better results than the average, and subsequent work elsewhere with the process justified the confidence of the engineers in its merit.

SLIME PLANT.

In 1906 the Minerals Separation, Ltd., purchased from the Block 10 company 60,000 tons of high-grade slime, and began the erection of a plant to treat this sort of material on a joint arrangement with the Sulphide Corporation, which company had large dumps of the same sort. This venture was one of the most interesting in the history of the application of flotation processes. The material treated is practically all finer than 100-mesh, and 82% was finer than 200-mesh. The plant was built in 1907, and it was originally intended to re-treat the flotation-concentrate on tables, and separate the lead sulphide from the zinc sulphide. This re-treatment scheme failed, however, and there being at that time no market for the mixed concentrate, the

plant was shut down. During 1909 there was some demand for the mixed product on the part of zinc buyers and for experimental smelting* work on mixed sulphides, and the plant was run for a time. In 1910 a market was opened in Norway for mixed lead-zinc concentrate, and the plant was operated long enough to fill a contract. The three years' operations are shown in the following table :

		FEED ASSAY			CONCENTRATE ASSAY				RECOVERIES		
YEAR	Tons	Zn %	Pb %	Ag Oz	Tons	Zn %	Pb %	Ag Oz	Zn %	Pb %	Ag %
1908	4,382	20.9	17.9	17.2	1,912	25.0	26.0	33.1	69.1	62.9	63.6
1909	2,179	19.7	16.8	19.3	1,109	32.5	21.4	28.2	84.0	64.7	74.6
1910	18,395	20.7	17.6	20.8	10,164	32.2	22.4	29.6	85.8	70.5	78.6

It is safe to say that such excellent recoveries on such a slimy material in a concentrate practically pure sulphide were never before secured by any form of mechanical concentration.

NEW CENTRAL MILL.

During 1906 there was under construction a new concentrating mill on the Central mine at Broken Hill, which was so designed that it should receive the ore by bucket-tramway from the mine, and turn out finished lead concentrate from the lead section ; and then, taking the tailing from the lead section, treat it by the Minerals Separation process, and produce finished zinc concentrate, all in one continuous operation.† Two units of the Minerals Separation process of the old type were installed in the zinc section, and the plant started in 1907. Fig. 49 is a flow-sheet of this plant. In 1908 the plant operated continuously with good results, although the concentrate produced from this plant was not of so high a tenor in zinc as the other plants, because of the high iron sulphide content of the ore, and also, perhaps, because some of the gangue minerals have a greater tendency to float when freshly crushed than after they have lain in the dumps for some time. In 1910 alterations in the type of machine were made, and mixing and frothing boxes of the type described in the beginning of this chapter were installed. The capacity of the plant was thereby increased. The tailing is taken from the lead section with all the mill water, and is first drained on a belt, and then the slime goes

*_Engineering & Mining Journal_, Vol. xc., 1910, August 13, p. 323–324.
† 'Annual Report for the Department of Mines of New South Wales for 1906,' p. 89.

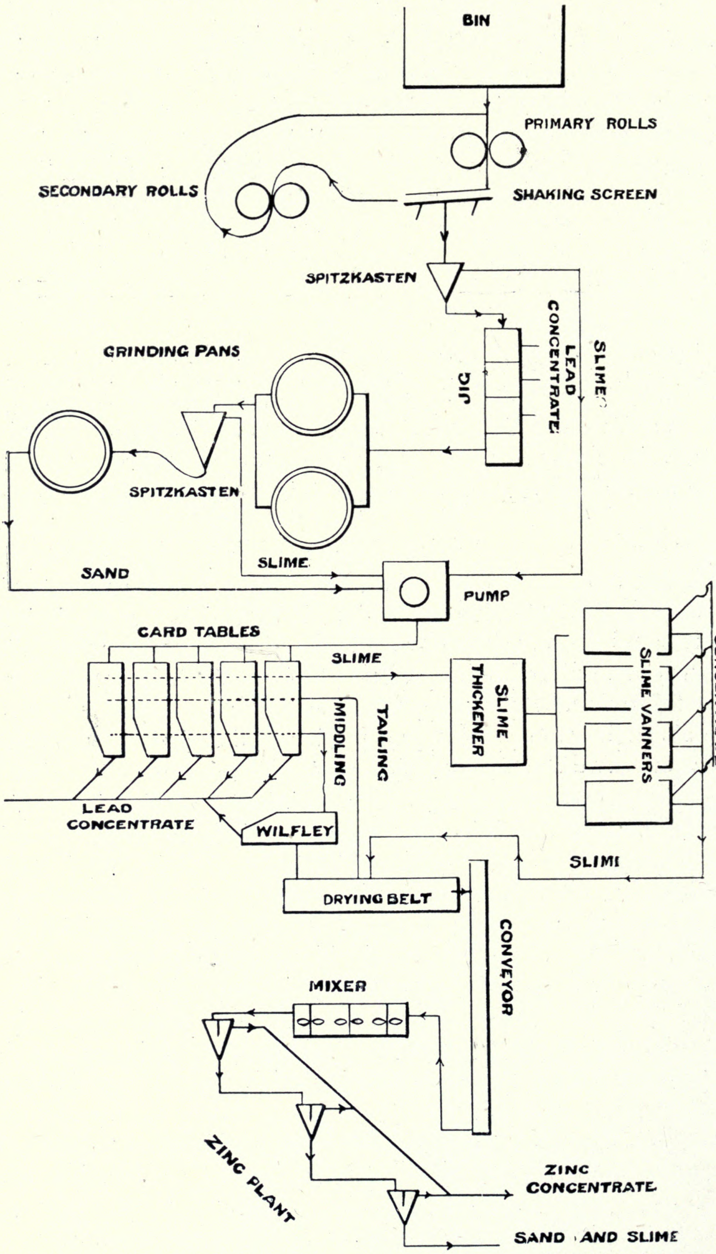


FIG. 49.—Flow-Sheet Central Mine Plant.

to tanks to settle. From the tanks and the draining-belt the material is fed by belt-conveyors to the flotation section, where the treatment is as previously described. No crushing is required, as the material is sufficiently fine from the lead operations.

Fig. 50 is a photograph of the dump. The results of the four years' work are given in the following table. The columns showing the zinc content of the concentrate and the recovery columns are a fine study in persistence. It was difficult to account for the grade of concentrate being low in this plant for the first two years. The table shows the improvement.

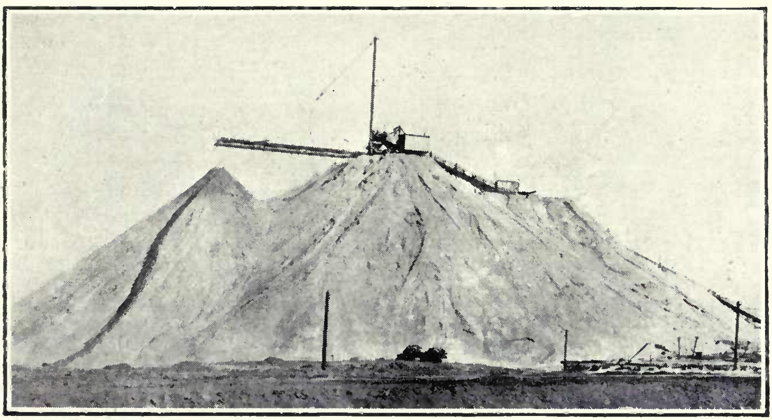


FIG. 50.—Tailing Heap of Central Mine.

		FEED ASSAY				CONCENTRATE ASSAY			RECOVERY		
YEAR	Tons	Zn %	Pb %	Ag Oz	Tons	Zn %	Pb %	Ag Oz	Zn %	Pb %	Ag %
1906-7	28,275	19.3	6.3	8.6	6,894	36.9	12.6	15.1	46.5	49.3	42.5
1907-8	157,142	20.5	6.1	9.1	54,842	40.4	13.1	17.7	68.9	75.7	67.6
1908-9	157,907	21.4	6.0	8.6	67,981	42.5	11.4	16.6	85.5	82.5	83.8
1909-10	227,126	20.7	6.1	6.8	88,767	43.5	11.2	14.0	82.2	72.0	80.5
1910-11	186 070	19.3	5.6	7.1	71,667	42.7	10.9	14.7	85.4	74.8	80.1
1911-12					69,326	46.3	8.7	16.0			

Several thousand tons of slime from the dumps has been treated in this plant, in addition to the slime in the material coming from the lead mill. In July, 1911, a re-treatment section was started; and, in addition to the zinc concentrate produced in the last year, there was recovered from the lead-mill tailing 2,941 tons of lead concentrate assaying 48.1oz. silver and 61.4% lead.

MINERALS SEPARATION, LTD.

In 1906 this company bought a large dump of lead-mill tailing from the Sulphide Corporation, and during 1907 a plant was constructed.* Profiting by lessons learned from earlier experiences, this mill did good work from the start, and has treated nearly 560,000 tons of dump material assaying 20% zinc, 6.2% lead, and 5.9oz. silver, and produced 218,000 tons of concentrate assaying 47.3% zinc, 9.8% lead, and 11oz. silver. No re-treatment of the concentrate is given in this plant. The cost in this plant over a typical period was as follows :

	s.	d.
Tramming		6.48
Crushing	1	8.45
Flotation	4	5.84
Disposal of concentrate		6.62
„ tailing		4.46
Total	7	7.85

Of these items the one for 'flotation' is of chief interest, and is made up as follows :

	s.	d.
Power		5.47
Acid	1	0.13
Oil		6.48
Supplies		5.18
Labour and salaries		3.06
Fuel for heating		5.16
Assays		1.22
Water		3.20
Repairs (labour and supplies) ..		6.31
General expense		5.63
Total	4	5.84

ZINC CORPORATION, LTD.

This company tried the Minerals Separation process in 1907, after abandoning the Potter process. The Minerals Separation process was rejected in turn, and the Elmore process installed, which latter process was used successfully for two years, when the

*_Engineering & Mining Journal_, April 30, 1910, p. 913, 'Oil Process at Broken Hill.'

Minerals Separation process was again adopted at the beginning of 1911. The Minerals Separation process had shortly before this time been considerably improved as regards its mechanical operation, and had demonstrated its adaptability to the slimiest material.

The cost for a typical period is as follows :

	s.	d.
Tramming	1	4.78
Grinding	1	3.41
Flotation	4	3.79
Re-concentration		8.97
Handling concentrate		4.94
Handling tailing		4.13
General expenses		8.72
Total	9	2.74

Of these figures the one for 'flotation' is of chief interest, and is made up as follows :

	s.	d.
Power		1.74
Acid		9.10
Oil		6.00
Supplies		3.50
Labour and salaries		2.22
Fuel for heating		5.42
Assays		0.30
Water		1.50
Repairs		8.90
Royalty	1	1.11
General expense (half)		4.36
Total	4	8.15

In all the company owns 27 dumps, most of which are either of a refractory nature, or are slime dumps ; and, seeing that all have to be removed by a given time, it is necessary to take a certain amount from each.

The cheapest and easiest way of removing these dumps is an important problem. At first sight a mechanical means of handling the tailing suggests itself, but as only a small portion of the daily tonnage treated is taken from each dump, it would never pay to

incur a heavy capital expenditure on a mechanism which would be worked considerably under its capacity. As these dumps are scattered over a large area, extending from the north to the south end of the Broken Hill district, the material is hauled (with the exception of the South mine tailing-dumps, which have been equipped with an aerial tram) by the Silverton Tramway Company in its railway trucks. A tram-track is laid into each of the dumps, and at a height a little above the top of the truck a loading gantry or staging is erected; this staging is hinged on the dump side of the track, and can be lifted by means of a small block and tackle to allow the locomotive to pass. The trucks supplied by the Silverton Tramway Company are strong iron cars of the box type, 15-ton capacity, 15ft. by 7ft. 6in., with doors at each side opening in the centre about half the length of the side, leaving a quarter standing vertical at each end. These trucks are certainly not the most suitable type, and entail much labour to empty, all of which has to be done by shovelling. A gang of men (the transport gang) are kept constantly employed at this class of work; and, in addition, they unload all coal, mine stores, etc. As the dumps are so scattered, the company is compelled to lay quite a quantity of tracks both to the dumps and at the works, which at the present time amounts to 22,000ft. The tramway company has set (subject to approval) a time-table each week, stating the number of trucks required from each dump, and the time suitable to both parties, namely, the contractor loading and the tramway company sending the empty trucks to each dump to be filled. The trucks, on arrival at the works, pass over a Pooley weighbridge, capable of weighing 40 tons, and after being weighed and then sampled for assay and moisture, the tailing is emptied into two storage-bins, having a total storage capacity of 1,888 tons (No. 1, 666 tons; No. 2, 1,222 tons). These bins are excavated out of the ground and made of concrete. At the bottom of the bins are openings, which deliver to 16 Challenge feeders (size of table, 2ft. 6in. diam., 15 r.p.m.). No. 1 bin has 10 feeders; No. 2, 6 feeders. By means of the Challenge feeders the millman is able, to some extent, to mix the material from the various dumps. The Challenge feeders deliver to a conveyor-belt, one to each bin parallel to it, and these again deliver to another conveyor-belt at right angles to the bin conveyors, which conveys the tailing up the hill, first to a rubbish trommel (8ft. 6in. by 4ft. by 2ft. 6in., 21 r.p.m.) clothed with a punched plate,

having 2in. holes; this trommel is for the purpose of removing any stones, large chips, and lumps of slime or any large size material that would interfere with the feeding arrangements from the mill bins, or which would be too coarse to enter the tube-mill feed-pipes, and so cause serious chokage. The product through the trommel passes to another conveyor, No. 4, 24in. wide, troughed 6in., running 363ft. per minute, and then to another conveyor running at right angles to these over the top of the bins. This belt is fitted with an automatic Robins distributor or take-off, which distributes the material evenly over the bins, and is of great assistance in mixing the material.

The following is a statement giving classification tests, assays, and metal content of the feed to the crushing section for the three months ended December 31, 1911:

		Percentage Weight.	Assays. Zn.%	Assays. Ag. oz.	Assays. Pb %	Percent. metal distribution. Zn	Percent. metal distribution. Ag	Percent. metal distribution. Pb
Original		100	16.4	7.7	7.0	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	37.7	14.1	7.4	7.9	32.4	36.2	42.5
,, 100	,, 0.16	35.4	16.7	5.7	5.3	36.0	26.2	26.8
,, 150	,, 0.09	8 9	17.8	6.8	5.6	9.6	7.9	7.1
,, 200	,, 0.06	2.8	19.9	8.0	5.0	3.4	2.9	2.0
Thro' 200	0.06 to 0	15.2	19.9	13.2	10.7	18.4	26.0	23.2

All assay figures are in terms of total metals; dry screening done on Hoover laboratoiy sizer.

From the mill bins, which have a total capacity of 874 tons, the material is automatically fed by means of four Challenge feeders (2ft. 6in.), running at 6.25 r.p.m. to chutes leading to three elevators 16in. by 8-ply Balata belting, travelling 380ft. per minute. These elevators deliver to six revolving screens clothed with brass woven wire, 12 by 12 mesh and 21 gauge; the over-size goes to the tube-mills, and the through product, which needs further grinding, to eight grinding pans, which are fitted with Freeman classifier pipes.

The discharge from the tube-mills (size of mill approximately 10 by 5ft., lined with ribbed liners, running at 24 r.p.m.), together with the material from the pans, runs to a Callow settler 8ft. diam. by 9ft. deep, fitted with annular overflow, for thickening; the overflow from this settler runs to four more 8ft. Callow settlers for de-watering, the clear water returning into circuit, while the

thickened slimy product runs through a small spigot, and unites with the thickened pulp coming from the single settler first mentioned; then to an elevator (size 16in., 8-ply, 300ft. per min.), which delivers to the mixer-box for flotation.

The following table gives the details of the material after crushing, showing classification tests, assays, and percentage metal distribution of the feed to the flotation plant for the three months ended December 31, 1911:

		Percentage Weight.	Assays. Zn. %	Ag. oz.	Pb %	Percent. metal distribution Zn	Ag	Pb
Original		100	16.4	7.7	7.0	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	2.2	10.3	4.6	3.0	1.4	1.3	0.9
,, 100	,, 0.16	38.6	15.3	4.8	3.9	36.0	24.1	21.5
,, 150	,, 0.09	16.6	17.2	6.7	5.9	17.4	14.4	14.0
,, 200	,, 0.06	6.0	18.6	7.6	5.8	7.8	6.6	5.7
Thro' 200	0.06 to 0	35.7	17.7	11.6	11.6	38.5	53.8	59.1

All assay figures are in terms of total metals; dry screening on a Hoover laboratory sizer.

The mixer-box is divided into 16 compartments, eight of which are for mixing and eight for flotation; the mixing is done in each of the compartments (3ft. square) by means of an impeller or paddle, 2ft. diam., working horizontally on a vertical shaft, having a speed of 306 r.p.m. From the mixer-box to the flotation-box there is an opening, 14 by 4in. and 12½in. from the bottom of the box, as an outlet from the mixer-box to the flotation compartment.

At No. 1 mixer-box the acid solution, the eucalyptus oil, and the steam for heating are added. The feed running into No. 1 mixer-box receives a certain amount of agitation by means of the horizontal impeller before it passes into No. 1 flotation compartment. The feed, being mixed with the acid and oil, becomes emulsified, and causes immediate flotation of a fair proportion of the sulphide particles, which flow over the lip of the flotation compartment into a launder. The rest of the material which has not been lifted falls to the bottom of the flotation compartment, and from there it is drawn by means of No. 2 impeller into No. 2 mixer-box through a 5in. pipe, and after receiving a certain amount of agitation and aeration it is forced into No. 2 flotation compartment, and a further amount of sulphides is floated off into

the launder. This zig-zag track is continued through the length of the mixer-box until it reaches the last flotation compartment, and by that time all the free sulphides should be removed; there only remains the residue, which is removed by opening a valve at the bottom of the last flotation compartment. This valve regulates the whole of the flow through the boxes, and has to be adjusted according to the proportion of water to feed, which is 3.5 of water to 1 of tailing by weight.

The following is a statement showing classification tests, assays, and percentage metal distribution of the flotation concentrate for three months ended December 31, 1911:—

		Percentage Weight.	ASSAYS. Zn. %	Ag. oz.	Pb %	Percent. metal extraction Zn	Ag	Pb
Original		100	41.8	15.3	12.1	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	1.7	47.1	11.4	6.0	1.9	1.3	0.8
,, 100	,, 0.16	46.9	43.8	11.3	9.0	49.1	34.6	34.9
,, 150	,, 0.09	13.9	41.7	13.5	11.3	13.9	12.3	13.0
,, 200	,, 0.06	4.2	43.3	15.3	11.1	4.4	4.2	3.9
Thro' 200	0.06 to 0	33.3	38.8	21.9	17.1	30.9	47.7	47.1

All assay figures are in terms of total metals; dry screening on a Hoover laboratory sizer.

Sectional samples taken from each of the flotation compartments when overflowing at the lips are very interesting, as will be seen by referring to the following table:

SECTIONAL SAMPLING OF M.S. FLOTATION-BOXES FOR PERIOD JANUARY 30 TO FEBRUARY 13, 1912.

	ASSAYS. Zn. %	Total Metals. Ag. %	Pb %	Oxidized Metals. Zn. %	Pb. %	Insoluble. %
No. 1 Box ..	38.6	31.9	17.3	0.4	2.8	6.3
,, 2 ,, ..	43.7	21.1	13.7	0.4	2.4	2.7
,, 3 ,, ..	46.1	17.1	11.2	0.3	2.1	2.2
,, 4 ,, ..	46.1	15.7	10.6	0.3	2.3	2.5
,, 5 ,, ..	44.8	15.1	10.6	0.4	2.8	4.1
,, 6 ,, ..	41.4	15.8	11.6	0.4	3.7	7.0
,, 7 ,, ..	39.3	15.7	12.4	0.4	4.0	9.0
,, 8 ,, ..	32.4	15.0	13.8	0.6	5.1	17.3

No. 1 compartment contained a high percentage of lead, and also of insoluble matter, and it was found that 7 and 8 also contained such a high percentage of insoluble matter that it was necessary to return these to No. 1 mixer-box again for re-flotation, with beneficial results. If was found, however, that, in spite of all the precautions, a high percentage of insoluble matter came over with the float, with certain ores, particularly those containing granular garnet. It is difficult to obtain a high-grade final zinc concentrate from these ores, although they are easily floated, requiring very little acid and oil. With the object of further raising the grade, it was decided to re-float the whole of the concentrate obtained from the first two units of the plant by passing it into a third flotation unit. The results obtained by re-floating the whole of the flotation concentrate from the two units have been very satisfactory, and can easily account for about a 2% rise in the zinc content of the ultimate flotation concentrate. At the time of writing the results obtained from a 14.8% zinc feed are approximately 42% zinc flotation, 44% re-flotation, and 46.5% finished zinc from the de-leading plant.

The following statement shows classification tests, assays, and percentage metal distribution of the re-flotation concentrate for two months ended December 31, 1911 :

		Percentage	Assays.			Percent. metal distribution		
		Weight.	Zn.%	Ag. oz.	Pb %	Zn	Ag	Pb
Original		100	43.2	15.7	12.2	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	1.3	45.1	12.0	6.7	1.4	1.0	0.7
,, 100	,, 0.16	42.1	46.5	10.7	8.5	45.3	28.7	29.3
,, 150	,, 0.09	11.7	43.4	13.0	11.0	11.7	9.7	10.5
,, 200	,, 0.06	4.6	44.2	15.1	10.3	4.7	4.4	3.9
Thro' 200	0.06 to 0	40.3	39.8	22.1	17.0	37.1	56.7	56.2

All assays are in terms of total metals : dry screening on a Hoover laboratory sizer.

The following statement shows classification tests, assays, and percentage metal distribution of sand-residue for three months ended December 31, 1911 :

		Percentage Weight.	ASSAYS. Zn.%	Ag.%	Pb %	Percent. metal distribution Zn	Ag	Pb
Original		100	2.4	2.7	4.3	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	9.5	4.9	3.3	3.4	19.4	11.6	7.5
,, 100	,, 0.16	51.1	2.2	2.2	3.1	46.8	41.6	36.8
,, 150	,, 0.09	12.1	1.7	2.2	3.7	8.6	9.9	10.4
,, 200	,, 0.06	4.0	1.6	2.9	3.9	2.7	4.3	3.6
Thro' 200	0.06 to 0	23.3	2.4	3.9	7.5	23.3	33.7	41.0

All assay figures are in terms of total metals ; dry screening on a Hoover laboratory sizer.

The following statement shows classification tests, assays, and percentage metal distribution of re-flotation residue for three months ended December 31, 1911 :—

		Percentage Weight.	ASSAYS. Zn.%	Ag, oz.	Pb. %	Percent. metal distribution Zn	Ag	Pb
Original		100	33.6	13.6	13.4	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	2.9	45.8	7.3	5.4	4.0	1.6	1.2
,, 100	,, 0.16	52.2	36.8	10.0	10.8	57.2	38.4	42.1
,, 150	,, 0.09	13.1	29.6	14.1	14.6	11.5	13.6	14.3
,, 200	,, 0.06	5.2	32.7	15.5	14.0	5.1	5.9	5.4
Thro' 200	0.06 to 0	26.6	27.6	20.9	18.7	21.9	40.9	37.1

All assay figures are in terms of total metals ; dry screening on a Hoover laboratory sizer.

As so much depends on the careful running of the flotation plant, special men are picked for this particular work, so as to get the best efficiency and to avoid waste of acid and oil. The workman has to watch carefully the amount of acid used, and he can do this by keeping the solution in Nos. 7 and 8 flotation compartments slightly acid, or almost neutral. He tests this periodically with methyl orange, and can easily detect any change in the quantity of acid required. With regard to the eucalyptus oil, he is guided entirely by the way the float is coming off; the temperature he keeps to 118° F., which is easily regulated, having the steam direct on to the No. 1 mixer-box. Probably the most important point of all is the necessity for having a solution not too dense ; if the

density of the solution exceeds 3,000 grains per gal., the flotation invariably goes off. To avoid this the workman periodically takes samples of his solution and tests it by hydrometer, and by reference to the following table he can quickly determine the density :

TABLE FOR ESTIMATING SOLUBLE SALTS.

Density at 60° F.	Salts in Grains per Gal.
1026	2000
1028	2200
1030	2350
1032	2530
1034	2700
1036	2900
1038	3050
1040	3230
1042	3400
1044	3600

The solution in circulation should not contain more than 3,000 grains per gallon.

CORRECTION FOR TEMPERATURE IN GRAINS PER GALLON.

Temp. Fahr.	Add. Grains.	Temp. Fahr.	Add. Grains.	Temp. Fahr.	Add. Grains.	Temp. Fahr.	Add. Grains.
61	3	71	83	81	200	91	323
62	6	72	94	82	212	92	336
63	12	73	105	83	225	93	350
64	18	74	117	84	236	94	364
65	25	75	128	85	248	95	378
66	33	76	140	86	260	96	393
67	42	77	152	87	273	97	408
68	50	78	165	88	285	98	424
69	60	79	177	89	298	99	442
70	70	80	190	90	310	100	460

To keep the density of the solution within the limit a clear-water pipe is attached to each mixer, and is used not only for this purpose, but also for make-up water. The usual custom is, as soon as the solution becomes too dense, to run off one or more of the slime-residue settling-tanks, and make up the balance with clean water again. This serves the purpose of getting rid of the slime-residue, as well as of improving the solution.

The re-flotation concentrate from the third unit is run direct to a conveyor or draining belt, 36in. wide, working in an iron trough 38in. wide and 15in. deep, for the purpose of draining. The overflow from the trough, which is always very fine and slimy and has a tendency to float, is run to an elevator 12in. by 8-ply, running 300ft. per min., and returned to a settler 8ft. diam. and 9ft. deep for thickening. A spray of clean water plays on the float material in the settler to break it down ; the thickened product from the spigot at the bottom is delivered to the same conveyor near the delivery end, and the overflow from the settler is run back into circuit.

The re-flotation concentrate coming off the conveyor-belt drops into a launder ; some water from the de-leading section is added to wash it down to an elevator 18in. by 8-ply, running 320ft. per min. It is thus elevated to pass over five revolving screens (clothed with 60 by 61-mesh and 36-gauge, running at 11 r.p.m.), and forms the feed to the de-leading section. The re-flotation concentrate, while being washed down this launder, is calibrated by turning the whole of the flow for a timed period into a large box, where it can settle, and the water can be decanted. This calibrating is done at regular intervals, and forms an *estimated* tonnage prior to de-leading.

The over-size from the revolving screens runs to a revolving distributor, then to 7 of the first row of Wilfleys (running at 310 r.p.m.) for treatment. The under-size runs to a distributor, then to 12 of the second and third rows of Wilfleys (running at 310 r.p.m.), six in each row. These tables make a lead and a zinc concentrate, a middling, and slime. The zinc and the lead concentrates each run to their respective elevators, and are delivered into separate tanks for settling and draining. The middling from the first row of Wilfleys is returned by means of an elevator (16in. by 8-ply, 280ft. per min.) to three Wilfleys on the same row, and re-treated, making a zinc and a lead concentrate and a small portion of middling, which is returned. From the second and third row of Wilfley tables come a zinc and a lead concentrate, also a middling and slime.

The middling from the second and third rows of Wilfleys is returned by two elevators (16in. by 8-ply, 280ft. per min.) to eight of the tables in the second and third row, four in each row, and re-treated for a zinc and a lead concentrate, a small portion of middling being made, which is returned.

The slime from the three rows of Wilfleys is run to two 9 by 18in. 3-throw plunger-pumps, running at 32 r.p.m., and pumped to six Callow settlers; the thickened product is run to 12 Weir-Meredith vanners, which make a lead and a zinc concentrate, a middling, and slime. The middling is returned to two Callow settlers, then to five vanners again, and the slime made on all the vanners is pumped to the dam on the flat for future sale or treatment. This slime, although high enough in zinc to go with the zinc concentrate, is so difficult to drain that it was found advisable to store it rather than include it with the coarser concentrate. If it was included with the zinc concentrate, the moisture in the shipping concentrate would be excessive, involving a penalty on all excess moisture over 6%. This zinc slime, which is high in silver and lead (see analysis of zinc slime), is a saleable product by itself, and some has already been sold.

The following table gives an analysis of fine zinc concentrate for three months ended December 31, 1911:

	%
Zinc	35.3
Lead	12.3
Iron	6.8
Manganese	1.5
Sulphur	23.9
Insoluble	13.1
Lime	1.5
Carbon dioxide	2.3
Silver	21.5 oz. per ton

CLASSIFICATION TEST.

Mesh.	Aperture.	Percentage Weight.
On 40	On 0.5	–
,, 100	,, 0.16	4
,, 150	,, 0.09	1
,, 200	,, 0.06	2
Thro' 200	0.06 to 0	93

The overflow water from both the zinc and lead concentrate settling-tanks runs to five Callow settlers; the thickened product

from these runs to the slime-pumps, and is re-treated on the vanners. The overflow runs to two large settling-tanks, 60ft. in diam. and 4ft. deep, having an annular overflow. These tanks are built of concrete, and have sufficient area to thoroughly clarify the slime-water. The clarified overflow water runs to two 3-throw 9 by 18in. plunger-pumps, and is pumped to the de-leading section supply-tanks, of which there are two, having a capacity of 10,000 gal. each ; it is from these tanks that the wash-water for the screens, Wilfley tables, and vanners is supplied. The residue-sand coming from the No. 8 compartment of the flotation section runs direct to two Callow settlers, 8 by 9ft., having an annular overflow, the material passing over going to the elevator carrying the feed to the mixer, while the thickened product is drawn from the bottom, and runs to a 36in. conveyor draining-belt working in an iron trough ; the overflow from the iron trough is pumped by means of a 4in. Robinson centrifugal pump to four round tanks, and the residue-slime allowed to settle. These residue-slime tanks (18ft. diam. and 4ft. 6in. deep) are fitted with annular launders, the overflow going to two 9 by 18in. three-throw plunger pumps, which pump the water into the three supply-tanks (16 by 8ft., 10,000 gal.), each elevated sufficiently high to supply the whole plant by gravitation. The residue-slime from these tanks is pumped out by means of a 6 by 12in. three-throw plunger-pump on to the flat, and forms a dam and bank around the main residue-dump.

The sand-residue is conveyed by two 36in. conveyors running slowly, 18ft. per min., to allow sufficient draining, and is dropped upon an 18in. by 5-ply conveyor-belt (rubber), travelling 210ft. per min., and conveyed for a considerable distance to a boom-stacker, which is building the sand dump to a great height.

Owing to the sloppy nature of the residue and the difficulty experienced in conveying it, also to the essential oil being a solvent of rubber, which quickly causes the belts to deteriorate, it has been decided to install a combination sluicing and conveying plant. By this scheme the residue will run direct to large draining-tanks, as far as the natural fall of the ground will allow, and then the residue, which will by this time have its moisture reduced to about 8%, will be conveyed the rest of the distance. By this scheme the conveying will be reduced by more than half and there should be less loss by evaporation, thereby effecting a saving in both belting and water.

The following is an analysis of lead concentrate for three months ended December 31, 1911:

	%
Zinc	15.7
Lead	55.2
Iron	3.4
Manganese	0.6
Sulphur	19.0
Insoluble	2.8
Silver	35.7 oz. per ton

CLASSIFICATION TEST.

Mesh.	Aperture.	Percentage Weight.
On 40	On 0.5	–
,, 100	,, 0.16	22
,, 150	,, 0.09	11
,, 200	,, 0.06	8
Thro' 200	0.06 to 0	59

The following table gives an analysis of zinc concentrate for three months ended December 31, 1911:

	%
Zinc	45.3
Lead	8.1
Iron	8.3
Manganese	1.6
Sulphur	29.5
Insoluble	4.3
Silver	14.8 oz. per ton

CLASSIFICATION TEST.

Mesh.	Aperture.	Percentage Weight.
On 40	On 0.5	1
,, 100	,, 0.16	32
,, 150	,, 0.09	11
,, 200	,, 0.06	8
Thro' 200	0.06 to 0	48

The finished lead and zinc concentrates (see analysis) from the de-leading section, after leaving the Wilfleys, are elevated into

draining-tanks (18 for the zinc concentrate and three for the lead concentrate). These tanks, which are fitted with filter bottoms by means of battens, cocoanut matting, and hessian, are emptied through a circular discharge at the bottom on to a conveyor (one conveyor to each three vats), which conveys the concentrate to another conveyor running at right angles to it, and is discharged into the shipping bins.

The capacity of each zinc-tank is 85 tons, of each lead-tank 125 tons, and the total capacity of the zinc and shipping bins 3,200 tons, making a total holding capacity of finished zinc concentrate 4,730 tons and of lead concentrate 575 tons. The shipping bins are built of stone, fitted with doors and chutes on both sides of the line for filling the shipping trucks; the extreme south end of the bin is partitioned off for the lead concentrate, and the same conveyor is used for conveying the zinc and lead concentrates alternately. After being filled into the Silverton Tramway trucks and sampled, the Zinc Corporation operations are finished.

The results of the operation of the Minerals Separation process in this plant is as follows:

	Tons Treated	Zn %	Pb %	Ag Oz	Zinc Concentrate Tons	Zn %	Pb %	Ag Oz	Lead Concentrate Tons	Zn %	Pb %	Ag Oz
1911	211,675	18.56	5.38	8.51	68,152	46.28	7.0	14.3	6,197	16.91	57.2	39.25
6 mos. 1912	171,005	14.9	5.8	7.3	44,229	46.9	7.6	13.1	5,254	13.9	59.4	33.7

Recovery—Zn 86% Pb 62.7% Ag 61.3%.

The Minerals Separation plants and their capacity now in use are as follows:—Sulphide Corporation, 700 tons; Zinc Corporation, 1,000; Kyloe Copper Mines, 60; Junction North, 600; Silver Peak, 80; Wallaroo and Moonta, 400; Etheridge, 80; Great Fitzroy, 250; Pinnicles, 160; Great Cobar, 400; Chillagoe, 200; Bradin, 1200; Cuba Copper Co., 150; Saxbergets, 150.

CHAPTER X.

Other Flotation Processes.

MACQUISTEN PROCESS.

One of the most important of the flotation processes is that invented by A. P. S. Macquisten. The apparatus is a tube so designed as to bring the sulphide particles in the ore on to the surface of the water in the most advantageous manner to insure that the force of surface tension and the inherent quality of the sulphides to resist wetting would insure their flotation.

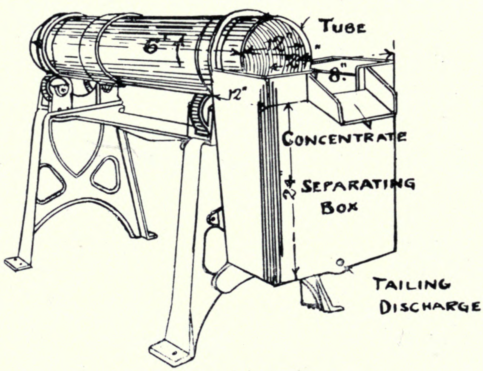


Fig. 51.—Macquisten Tube.

The tube, Fig. 51, is made of cast iron, 6ft. long and 1ft. in internal diameter.* Two tyres, cast with the outside, run upon rollers, upon which the tube rests. The discharge end of the tube is open, while the feed end is closed, except for a hole in the centre to admit the feed-pipe. On the interior of the tube is cast a helical groove of 1½in. pitch. The discharge end of the tube, at the right of Fig. 51, connects with a vessel called the 'separating box,' the joint between the box and the tube being watertight, although the tube is free to revolve. The box has an opening for

Engineering & Mining Journal, October 26, 1907, 'Concentration Upside Down,' by W. R. Ingalls.

the overflow of water, the lip of this opening being of such a height that about 3in. of water stands in the tube. The feed of pulp to the tube and the discharge of tailing at the bottom of the box are so regulated that the water passing over the lip of the box is about 1-32 in. deep. The floating concentrate passes over this lip into a launder, and the tailing passes out at the hole at the bottom of the box, going to a second tube for further treatment, if necessary, or to the tailing-flume. In operation the tube is rotated 30 r.p.m. in the direction of the helix. The pulp is thus screwed through the tube, and in its advance at every revolution the sulphides are given an opportunity to slide upon the surface of the water and float. As the tube revolves the pulp is carried up to the surface, and gently rolls over. The angle of emergence is such that some particles of sulphide are at once drained of the adhering water, take on air-films, and float. The gangue simply slides back into the water. This action is taking place at every corrugation, whereby the sulphide particles, which are capable of being held up by the force of surface tension, are given many chances to slide out upon the surface of the water at just the angle at which there is the least likelihood of penetrating the surface.

In any given tube revolving clock-wise (looking toward the feed end) the flotation takes place chiefly at the left-hand side, where the pulp emerges from the water. The bulk of the pulp in any corrugation either slides back into the water, or floats off; however, a certain amount always adheres to the tube, and is carried over to the water on the right-hand side, where upon meeting the water a further flotation takes place, but naturally this is less than on the left-hand side. Consequently, from the time the pulp enters the first tube there are floating sulphides streaming off from the sides of the tube, which by the time the discharge end is reached form a glistening film, covering the entire surface of the water both in the tube and in the separating-box. This is quite different in appearance from the black frothy scum which rises to the surface in the acid-flotation processes. In separating the chalcopyrite and pyrite at Golconda, the surface of the water is covered with the sparkling bronze mineral, the water looking as if it had been sprinkled with the bronze powder that is employed for decorative purposes. In treating a lead ore, there comes off a film of steel-grey galena; in treating a zinc ore from Joplin, Mo., there was a film of mustard-yellow blende. The flotation is persistent. Once it has been effected, the mineral

remains on the water until the latter has overflowed into the launder, which delivers it into the collecting-tank, and even in the latter more or less mineral can be observed floating on the surface. One treatment is not generally sufficient, and the gangue-tailing, with the remaining sulphide, is passed through a second, third, and fourth tube. By far the largest amount of concentrate is secured from the first tube.

The capacity of a single tube is 5 tons of ore per day, but as the material must be put through several tubes, the actual capacity of a set would be, say, 5 tons. The ore at the Adelaide mine assays from 2.7 to 3.2% copper, and the percentage of sulphides is low. It is important to note that on a heavy sulphide ore like that at Broken Hill it would probably be necessary to treat the material through a great many tubes, or else cut the capacity down to a very low point. These tubes have an effective flotation surface

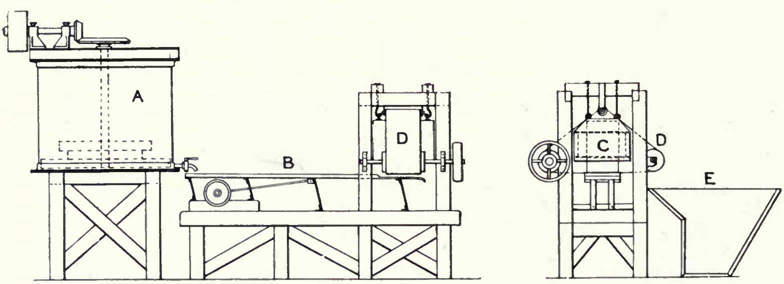


FIG. 52.—Murex Apparatus.

of 6 sq. ft. per tube; and, therefore, must be limited in capacity as compared with those processes which increase the available surface by froth production.

The accounts of this process so far published seem to indicate a lack of facility in the treatment of slime.

MUREX PROCESS.

This process is not strictly of the same class as the others; but as it makes use of the principle of the selective oiling of sulphide particles, and has other similarities to flotation processes, it should be described. In this process the crushed ore is fed to an agitator, Fig. 52. A 'magnetic paint' is fed with the ore in quantity ranging from 40 to 60lb. per ton (4 or 5%) of ore. This magnetic paint is made by mixing one part of oil or thin tar of almost any kind with three or four parts of magnetic oxide of iron, natural or

artificial. The oxide must be ground to an impalpable powder. In the mixer A the ore, with the paint and enough water to make a thick pulp, is agitated from five to twenty minutes to thoroughly mix the substances. The paint preferentially adheres to the sulphides because of its oily constituent. When this is accomplished the pulp is fed with some additional water to the upper end of the shaking conveyor B, along which it travels to the magnet C. Around the magnet C is an endless belt D, this belt being between the magnet and the conveyor. As the pulp passes along the conveyor it comes within the magnetic field, and the sulphide particles, partly due to their inherent magnetic permeability and partly to the magnetic permeability of the adhering magnetic paint, are drawn up against the endless belt D and carried outside the magnetic field, where they are washed into the launder E by a stream of water. It is claimed for this process that a great variety of products can be made by varying the material used for mixing with the magnetic oxide. We are already aware that the seriation of minerals, which exercise a preferential oiling, is of much wider range than the seriation of those which will preferentially float, and it is easily believed that among the thousands of oils and coal and wood tar derivatives there may be one which would preferentially adhere to almost any mineral chosen.

This process is a new departure, and well worth research and development. At first glance the successful treatment of oxidized ores, not now treatable by any other process, would seem to lie in this direction. Whether the process could compete with gravity or flotation-concentration for sulphides at present lacks extended demonstration.

SANDERS PROCESS.

This process, tried at Marion, Ky., is somewhat different from the other flotation processes, inasmuch as no acid is used in the bath, the latter being, on the contrary, basic, being in fact a very dilute solution of aluminium sulphate. Moreover, instead of being performed in deep vats, as in the case of the acid-flotation process (wherein the depth of the vat has been found to be a rather important consideration), the basic flotation process is performed in shallow pans, in which mechanical stirrers are operated. Besides the trials at Marion, some experiments with the Sanders process have been made by the Tennessee Zinc Company at Straight Creek, Tenn. The Kelly mine, near Magdalena, N.M., was equipped with a 100-ton plant.

The apparatus (Fig. 53) consists of a vat, preferably round, with a feed-hopper leading below the normal liquid surface. A solution-inlet pipe is placed either in the vat or in the hopper, depending on the ore to be treated. A vertical shaft in the centre of the vat rotates an agitator, the blades of which are arranged to impart a whirling motion to the solution. This whirling motion

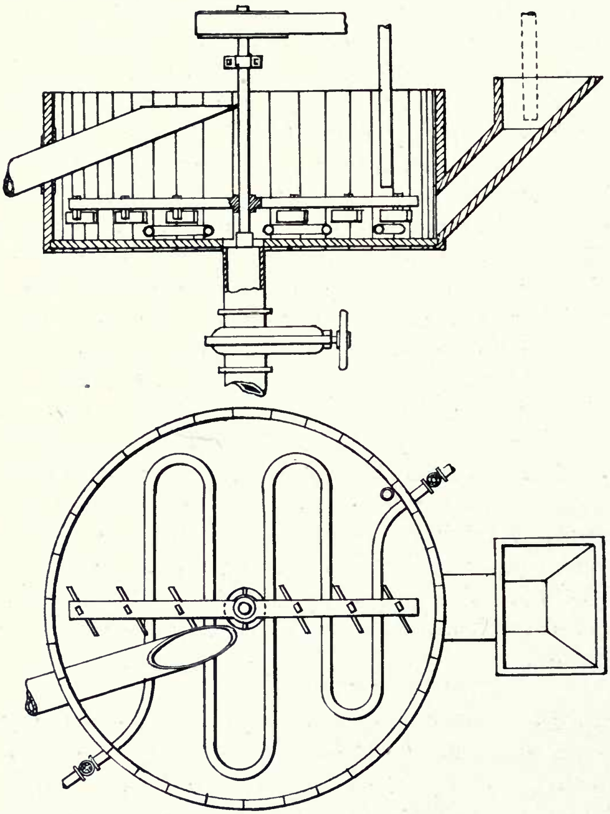


FIG. 53.—Sanders Apparatus.

is designed to assist in raising the valuable mineral particles to the centre of the vat, and to cause a slight cavitation at the centre of the surface, which causes the particles which have been elevated to pass at once to the overflow pipe. The tailing is discharged through a pipe in the centre of the bottom of the vat. A steam-pipe is used on the bottom of the vat to keep the solution at an even temperature.

HORWOOD PROCESS.

The principle of this process is that when a mixture of iron, copper, lead, and zinc sulphides is roasted, the surfaces of the

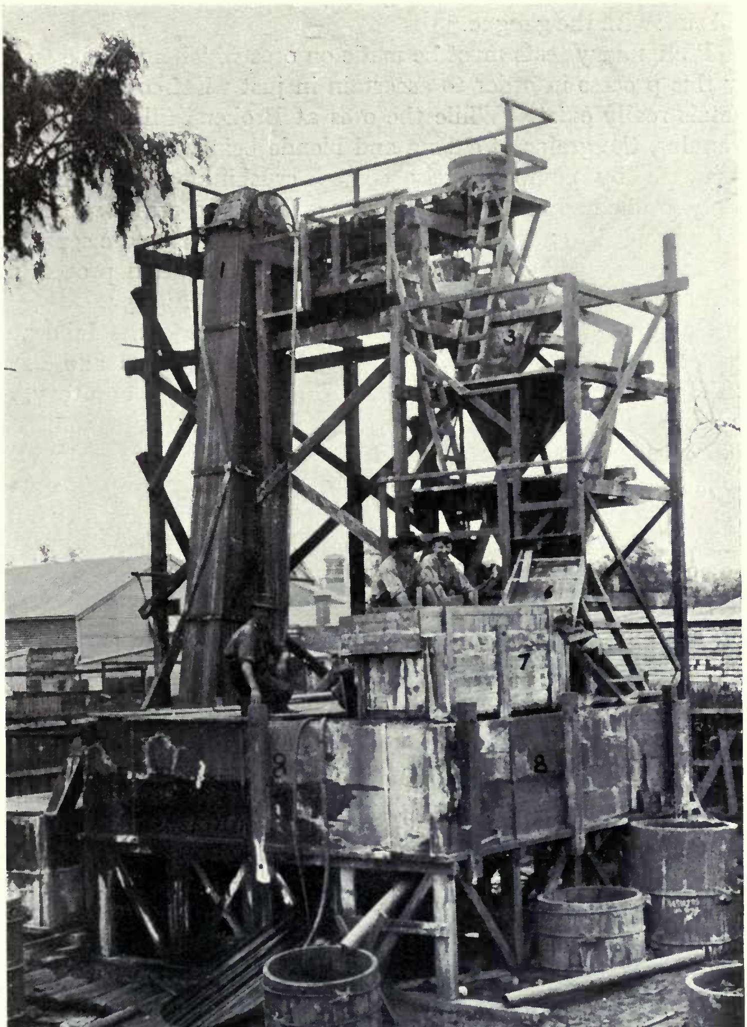


FIG. 54.—Horwood Experimental Plant.

particles of the three former sulphides are changed to oxide and sulphate at a comparatively low temperature, whereas the zinc

sulphide is practically unaltered. The partly roasted material is then subjected to a heated-acid oil-flotation process, such as the Minerals Separation process, when the zinc sulphides will float away, and the deadened or sulphated compounds of iron and lead will sink with the gangue.*

Preliminary tests must be made on ores which are to be treated by this process in order to ascertain in just what combination the metals really exist. While the ores at Broken Hill are somewhat granular, the grains of galena and blende being, to a great extent, separable by comparatively coarse crushing, there are many steely-grained admixtures of blende, galena, and pyrite which have to be reduced to a slime before the individual grains are separated.

A photograph of the small Minerals Separation process unit used in extended trials at Bendigo is shown in Fig. 54.

On one lot of Broken Hill slime concentrate the laboratory test showed the concentrate to contain 32.4% zinc and 22.3% lead. This was roasted and treated in the testing laboratory, and two products were made: No. 1, a zinc concentrate, containing 50.8% zinc and 6.3% lead; No. 2, a lead residue, containing 2.6% zinc and 49% lead. About 53½% of the original concentrate was recovered as a zinc concentrate, and about 38% reported as a lead residue. About 85% of the total zinc and 85% of the total lead were recovered in this test.

In actual operation there were obtained from this ore a zinc concentrate, containing 50.4% zinc and 7.3% lead, and a lead residue, containing 12% zinc and 41% lead. The lead residue may be improved by further agitation, raising the content of the lead and reducing that of the zinc.

A complex sulphide from Tasmania, containing an intimate mixture of blende, galena, and pyrite, was also tested. This ore had to be crushed dry to a slime product to insure separation of the blende and galena. The ore assayed 30.9% zinc and 9.9% lead, and yielded in actual operation in the experimental plant a zinc concentrate containing 57% zinc and 5% lead, and a lead residue containing 5.8% zinc and 20% lead. These Tasmanian ores were so intermixed that some mineralogists considered the zinc-lead sulphide to be an isomorphous compound.

Preliminary laboratory tests must be made on ores to be

*_Engineering & Mining Journal,_ February 26, 1910, p. 460, 'Horwood Process,' by Donald Clark.

treated by this method to determine the percentage of flotation obtainable, the amount of lead required to be converted to sulphate, acid consumption, crushing, etc.

The ore is roasted in an Edwards furnace, the temperature being kept below the ignition point of zinc sulphide ; usually the temperature of the heated gases passing over the ore, as tested by a pyrometer, varies between 300 and 400° C. The end point of roasting is determined by prior laboratory experiment, and varies with the composition and fineness of the ore. Tests are made from time to time on the furnace product to find the amount of lead present as sulphate, and as soon as the predetermined amount is reached the ore is discharged from the furnace.

In the first test the ore was roasted in charges until sufficiently sulphated ; but latterly, and with more satisfactory results, a continuous feed and discharge and a slow rabble-motion were used. The first to oxidize is the pyrite, and next the galena, the zinc sulphide being almost unaffected. The time required for Broken Hill slime-concentrate, when roasted in charges, was about three hours.

The partly roasted ore is fed into the boot of a bucket elevator with about five times its weight of a dilute solution of sulphuric acid, heated to near the boiling point. The amount of acid required is determined by laboratory experiment, and is as high as 100lb. per ton treated.

The zinc, being unaltered by the slight roast, floats at the surface as mineral froth in the same way as was described in Chap. IX., while the iron and lead particles, being altered on the surface to soluble sulphates, are wetted by the water and sink. It may be noted here that the extreme limit of water-wetting is the case of solubility.

Kenneth A. Mickle* proposes to get an analogous alteration of the galena particles by treating the crushed material with ferric chloride, and then subsequently treating by a flotation process.

HYDE PROCESS.

James M. Hyde, of Basin, Montana, has developed a flotation process for treating the ores of the Butte & Superior Company. The experiments at Basin were so successful that the Butte & Superior Company has erected a mill at Butte on lines laid down by Mr. Hyde.

**Australian Mining Standard*, May 2, 1912, p. 404.

The description of the process is given in U.S. Patent No. 1,022,085, as follows: The ore, after crushing, is mixed with acid before thickening in a tank A (Fig. 55). It has been found that adding the acid in advance cuts down the amount required,

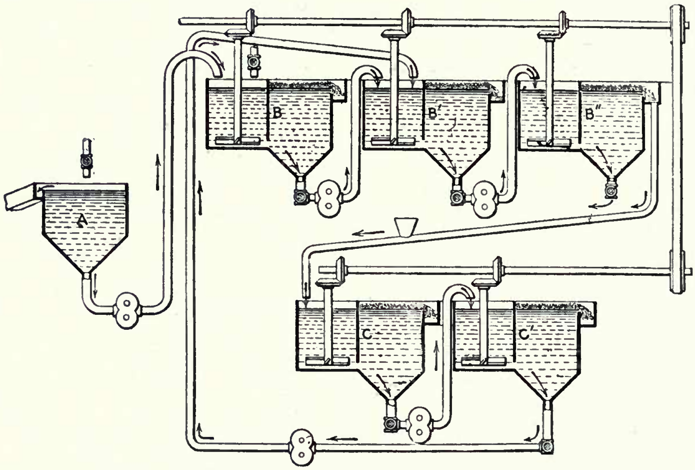


FIG. 55.—Hyde Apparatus.

and promotes the settlement of colloidal material, which may be further aided, if necessary, by adding copperas, alum, or some other coagulant. From the thickener A the pulp is pumped to the first treatment tank B, where oil is added and the entire mass agitated. A float concentrate is then taken off, and the gangue goes to the tank B′, where the process is repeated, and thence to B″, where the pulp is agitated and a third concentrate taken off. From B″ the gangue is discharged as a final tailing.

There is considerable silica mixed with the first concentrate, so it is re-cleaned in a second device CC′, the concentrate from which is the final product, while the tailing is all sent back to B′.

As an example of actual work with this machine, the following description is given: The material treated was the slimy portion of an ore, consisting principally of quartz, blende, and various amounts of decomposed granite, in which the felspars were largely kaolinized. About 92% of this material was fine enough to pass a 150-mesh screen. Without the use of a coagulant, part of the slime, containing a notable percentage of zinc, would remain in suspension over 24 hours.

The pulp, as produced, contained from 29 to 100 or more parts

of water by weight to one part of ore, to which was added, before thickening, from one-quarter to one-half pound of sulphuric acid per ton of ore. The thickened pulp was heated in the flotation machine by live steam to expand the gas bubbles, and facilitate coating the sulphide particles with the oil used, which, in this case, was 'candle-maker's red oil.' The oil consumption cannot be calculated beforehand, but must be gauged by experience. The ore fed carried 23.3% of zinc, the concentrate 51.4%, and the tailing 3.2%, indicating a 91% recovery. The concentrate from the primary section of the machine ran 38 to 42% of zinc.

The Butte & Superior ore contains rhodochrosite, quartz, and sulphides and is an ideal ore for flotation. The ore has been treated for some time at the Basin reduction plant, rented from the United Copper Company by the Butte & Superior Co. The mill was too small and the rental heavy, so plans were drawn for a 1,000-ton mill, one 500-ton unit of which was in operation by the end of May, the other about a month later. The installation consists of a crushing plant, jigs, hydraulic classifiers, a slime-plant for oil-flotation, and Wilfley tables, which are used only to separate the lead from the zinc. The ore is first reduced by rolls to 6-mesh, and, after jigging, the tailing is re-ground to 40-mesh, and the tailing from the fine jigs ground to 100-mesh, and treated by oil-flotation. The pulp is thickened to three parts water and one part ore, and is mixed with a small quantity of oil and sulphuric acid and agitated.

The following are the results of the operation :

EFFECT OF FINENESS OF FEED ON RECOVERY.

500 GM. TESTS.

	Feed. Assays	Conct. per cent.	Tail. Zinc.	% Recovery
Crude Ore through 60-mesh ..	18.8	51.1	—	83.0
	18.8	45.7	—	87.0
	22.6	47.2	2.4	92.7
	22.6	48.5	2.7	90.1
Crude Ore through 150-mesh ..	22.1	47.9	0.7	97.2
	22.1	52.8(a)	1.1	93.5
		Mids.	4.8	
Jig Tailing through 60-mesh ..	10.9	39.5	2.7	73.2
	10.9	42.0	2.8	75.5
Jig Tailing through 150-mesh ..	10.4	40.1	1.4	87.6
	10.4	48.9(a)	1.7	79.4
		Mids.	4.7	

(a) These concentrates are the only ones in the above series which received any cleaning re-treatment. The material marked ' Mids ' is the tailing resulting from this re-treatment. In actual milling, where the middling is returned to the rougher for re-treatment, it is found that the tailing is practically as low when the cleaner is used as when it is not, and the cleaned product runs 5 to 8% higher than the uncleaned.

SUMMARY OF FLOTATION TESTS.

	No.	Gal. treated per min.	Ratio water to ore.	Rate of Tons per day Ore.	Conc.	Assay. Feed.	Conc.	Tail.	Recovery. %
Complete Hyde Machine Regular Mill Feed	11	166.9	6.9-1	142.3	71.3	25.8	50.1	2.7	94.6
Rougher Hyde Machine Built up Feed	12	156.1	3.09-1	281.7	131.4	20.1	41.8	1.1	97.0
Rougher Hyde Machine Built up Feed	13	196.3 166.8	2.1	516.76 439.0	190.3 190.3	21.8	43.2	5.5	85.7

SCREEN-ANALYSIS OF MILL PRODUCTS.

BUTTE AND SUPERIOR ORE.

Mill Feed 21.1% Zinc. 500 gm. Sample, 4 days sample assay.

Crushed through 5 mm.

		Weight.	% Weight.	Assay % Zinc.
On	20	332.2	66.44	18.3
	40	56.7	11.34	19.4
	60	24.2	4.84	22.5
	80	11.5	2.30	23.5
	100	9.9	1.98	24.7
Through	100	61.9	12.36	24.9
		496.3		

COARSE MILL TAILING.

Sample for 2 days, 500 gm. Sample, 9.4% Zinc.

On	20	136.3	27.26	8.6
	40	183.8	36.76	9.7
	60	67.6	13.6	9.7
	80	34.6	6.92	8.9
	100	17.6	3.52	11.1
		497.4		

TABLE TAILING.

		Weight.	% Weight.	Assay % Zinc.
On	40	42.6	21.3	6.1
	60	29.1	14.5	4.9
	80	22.7	11.3	5.9
	100	24.5	12.2	5.1
	150	13.0	6.5	5.0
Through	150	64.2	32.1	11.3

SCREEN-ANALYSIS FLOTATION CONCENTRATE AND TAILING.

Concentrate No. 56 from ore assaying 22.6% Zinc. 100 gm. Sample.

Whole Sample, 47.2% Zinc.

		% Gms.	Fe.	SiO_2	Zinc.
On	80	16.0	3.2	24.8	43.6
	100	18.0	3.4	22.0	46.0
	150	14.0	3.6	20.2	46.4
Through	150	52.0	3.4	17.9	47.8

Concentrate No. 58, Ore as above.

Whole Sample, 48.5% Zinc.

		% Wt.	Fe.	SiO_2	Zinc.
On	80	13.5	3.1	21.7	46.6
	100	22.4	3.1	18.2	48.5
	150	9.8	3.2	16.4	49.5
Through	150	54.3	3.3	14.3	50.0

2.0% Zn Tailing No. 65 from Fine Jig Tailing 6.1% Zinc.

		% Wt.	Assay % Zinc.
On	80	26.7	3.9
	100	45.8	3.0
	150	16.5	2.6
Through	150	11.0	1.8

2.7% Tailing No. 59. From Mill Feed, 22.6% Zinc.

		% Wt.	Assay % Zinc.
On	80	20.8	4.0
	100	18.0	3.4
	150	14.5	2.7
Through	150	46.7	2.0

2.8% Zn Tailing No. 63. From Coarse Jig Tailing, 10.9% Zn

		% Wt.	Assay of Zinc.
On	80	23.4	4.0
	100	17.8	3.4
	150	9.7	3.0
Through	150	49.1	2.0

CHAPTER XI.

Economics.

Flotation processes have a restricted range of application. The development has been, and is, so rapid that no one can prophesy what the end will be. Up to the present comparatively few minds have been working on the idea, but with the wider human effort which within a few years will be brought to bear, it is quite likely that the applicability will be considerably increased. There is reason to believe, also, that the forces of surface tension and adhesion could be profitably employed in industrial operations other than ore concentration, and especially in operations where coagulation will give rise to new combinations. Buoyancy-flotation has already been applied to the separation of imperfect oranges from perfect ones, and also to the separation of wood fibre from *guyaule* rubber.

Limitations.—There are, in the present state of our knowledge, four main limitations to the applicability of these methods. The first is that in general they are limited in their usefulness to those ores where certain valuable metals are in the form of sulphides, which need to be separated from worthless gangue. Some flotation patents have claimed to be able to treat ores where the minerals are carbonates or oxides, but these claims are at the present time over-optimistic, and so far there is not any demonstrated method of concentrating carbonates and oxides by flotation. It is the metallic sulphides, as distinguished from the carbonates and oxides, for which the oils and gases used in these processes have a marked selective action. The carbonates and oxides are not without some adhesive quality, but this quality in them is so feeble on the one hand as compared with the sulphides, and so little differentiated from the adhesive quality of the gangue on the other, that it has been impossible so far to found a commercial process on this quality. This is an important point for research and invention, as it it quite likely that if a process was found by which the carbonates and oxides could be separated from gangue by flotation it would also obviate the second dominant limitation

of the process. The most likely line of research at present in sight that would seem as if it might accomplish the desired end is along the line of soluble frothing agents, and especially the multitude of little known products from the destructive distillation of various woods; a method which aims at coagulation of the mineral by means of slow agitation may also be beneficial.

The second limitation to the usefulness of the processes is that in general they are not applicable to ores which contain more than 5% of those carbonates which are soluble in dilute acid. For the acid-flotation processes a small proportion of calcium carbonate is a *sine qua non* for success in order that the acid may have something from which to generate carbon dioxide gas. Those processes which use air as the flotation gas do not need any carbonate present; it is a detrimental element in this case because it unnecessarily consumes acid. Four to five per cent. of calcium carbonate is the maximum required for acid-flotation processes; more than this unnecessarily consumes acid. The ideal ore for the acid-flotation processes is the Broken Hill tailing from the table concentrators, having the following analysis:

	%
Pb	7
Zn	20
Fe	8
Mn	3
S	14
CO_2	3
SiO_2	42
CaO	1
O, etc.	2

An ideal ore for oil-air flotation methods is that of the Guernica mine in Bolivia, which has the following analysis:

	%
Cu	3
Fe	12
S	10
Al_2O_3	2
SiO_2	72
O, etc.	1

This latter ore would require the addition of calcite in order to get any result with the acid-flotation processes.

Some ores which have up to 10% CO_2 can be successfully treated by the oil-air flotation processes by adding a small amount of acid at the proper moment of flotation; whereas an attempt to treat these ores by mixing them with a comparatively strong acid solution, such as is used in the acid-flotation processes, results in the consumption of all the acid in the circuit without getting the desired result. Some recent patents claim useful results without acid and the present practice at the Great Fitzroy mine in Queensland is of this order.

Ores like that of the San Francisco del Oro mine and the Avino mine in Mexico have proved difficult to treat, because these deposits occur in a calcareous country-rock, some of which is necessarily mixed with the ore. The former also contains fluorite, and this fluorite shows a decided tendency to float, thus contaminating the zinc concentrate with an element which the zinc buyers penalize most stringently. In this point, then, we have the third limitation to these methods—that is, they are limited to those ores which do not contain floatable minerals that are deleterious to the concentrate. Besides the fluorite ore mentioned above, the mixed sulphide ores of Scandinavia fall into this class because they contain such a large percentage of iron pyrite, which floats, that the tenor of the concentrate is thereby reduced to a point so low that the product is unmarketable. The market demand for concentrate also bears on the cases of graphite and molybdenite. There has been a great deal of unjustified optimism concerning the supposed revolution flotation processes would bring about in the treatment of these two substances. In the case of graphite the fine crushing tends to destroy one of the best qualities of the graphite, because the best prices are paid for the larger grains. There is a very limited market for slimed graphite, and in any case there is always some gritty quartz in the flotation concentrate which is deleterious for the chief purpose for which fine graphite is used, namely, lubrication. Graphite thus falls within the third limitation. Molybdenite is the most easily floated of all the minerals, but a plant of sufficient size to pay a profit on mining and milling would produce enough concentrate in a year to supply the present demand for a hundred years. It is true that a cheap high-grade molybdenite concentrate might build up a new market by making that metal available for new uses, but not at the present price of the concentrate.

The fourth limitation is one for which at present no adequate

reason can be given. An ore in which the valuable minerals are wholly or partly bornite or chalcocite, as those of Bingham canyon, will probably give trouble to flotation processes, although not always, for among the many ores tested the one which gave the most uniformly satisfactory results was a copper ore assaying 2.8% copper, all in the form of microscopic specks of bornite. The gangue of this latter ore was an acid dike rock, and it is just possible the bornite was an original constituent of the rock. There was no appearance in the ore to suggest oxidation, the whole mass being singularly free from fractures. The recovery on this ore was 95%, and the concentrate assayed 48% copper. It may be that only those ores where bornite and chalcocite are of secondary occurrence give trouble. It is true that good hand specimens of bornite, when finely crushed, can be made to float with ease. As a general rule, however, it will be necessary to carefully test copper ores which contain any bornite or chalcocite before pronouncing an opinion as to the probability of successful flotation-concentration. The Bingham canyon ore contains so little bornite or chalcocite that its presence often escapes superficial observation.

Separation of Sulphides.—Up to the present these methods have not with complete success solved the problem of the separation of the sulphides from each other. The Horwood process is a step in this direction, but little has been heard of it recently, and on economic grounds it is doubtful if in the present form the idea is commercially feasible.

The sulphides of the base metal have the quality of oil and gas adhesion in varying magnitudes, as can be easily demonstrated, but the range of this variability is much smaller than between gangue and sulphides. No one dare say, however, that even this minute variability does not have in it the basis of a commercial separation. Horwood accomplishes the result by going to the expense of a preliminary slight roast, and thus turning some of the sulphides as far as is necessary into a form analogous to gangue minerals, thus destroying the strong adhesive quality of some of the sulphides, and he thereby is able to separate them from those sulphides whose quality of adhesion to oils and gases is unaffected by the slight roast. This is another of the important unsolved problems, and its solution lies in the direction of combining all the favourable factors in such a way that they all act at the proper time and proper place. Some oils cause a better

frothing of the blende than of the galena ; some temperatures are better for the frothing of certain sulphides than of others ; some pressures cause a froth to form in which there is a greater proportion of certain sulphides than at other pressures ; the amount of air or gas made available for frothing affects the composition of the froth to a certain extent ; the amount of acid used has a decided influence on the constitution of the froth, and the impurities of the water also have similar effects. The above factors and others, which are available for working in conjunction, conceivably contain the secret of a revolutionary process for solving the long-standing problem of separating completely and commercially mixed sulphides of copper, zinc, and lead. I am inclined to think however, that the solution of this vexed problem lies within the realm of the chemical industry.

Combinations.—The limitations of any one process of ore concentration are the reasons why metallurgists have always used combinations of processes and of apparatus. We have combinations of hand sorting, jigs, shaking tables, vanners, and many others, and these combinations are further combined with amalgamation, cyanide, chlorination processes, and others. Flotation processes quite properly take their useful places in combinations for the purposes of concentration only, but it is not likely that they will soon be used in combination with the cyanide process ; at least, they will probably not be so used until a successful flotation process is discovered which does not use any acid. We would not at first glance think that health conditions would be good in a plant where cyanide treatment of the ore is either preceded or followed by one of the present flotation processes. Nor is it likely that a combination of an oil-flotation process followed by amalgamation will soon be seen, although there would appear to be nothing to prevent flotation-concentration following amalgamation provided cyanidation was not desired.

Slime.—This point will be discussed with some reluctance because the author's past relations have been such that there is a fear he may be charged with favouritism or with advertising a proprietary method. Even at the risk of this criticism it is just to the reader as well as the process owner to venture a private opinion, based on extended observation. One of the important processes previously described makes no attempt to treat slime, and numerous statements have been made in line with this fact. A second process described, while making, perhaps with some jus-

tice, claims of an ability to treat slime, has signally failed in at least two important instances unnecessary to specify. A third now seems to be in a way to overcome its earlier difficulties. Among the minor processes there does not seem to be any which have advanced far in the treatment of slimy material.

The Minerals Separation process has for some years stood alone in its ability to handle with ease in operation, and with commercial profit, the slimiest of mill by-products. This has been demonstrated by operations extending to millions of tons and over years of time. There are sound physical reasons for this feature and the principles involved—to wit, coagulation of the sulphides, followed by frothing of the coagules, are made the most of. It is unnecessary to give details on the subject of this slime treatment other than are found elsewhere in this and previous chapters. Recent developments of the Potter-Delprat process indicate for certain that slimes can now be treated successfully by this method also.

Magnitude of Operations.—It is a significant fact worth keeping in mind that nearly, if not quite, all the plants where these processes are now being used are very large plants. They are treating large tonnages at a small profit per ton, and if they were operating on the scale of the average sized mine, as will appear later, the overhead charges would probably eat up all this profit. In addition to this, the operations are on materials which have already been mined and which cost very little to deliver to the bin. If 10s or 12s per ton was added as the cost of mining to the working cost, the profit would disappear. The cost given later is mostly for the Broken Hill district, where the cost is much higher than is considered necessary elsewhere in the world. It seems probable that the same operations in the United States would be 25% less, even though the cost of materials is about the same and wages much higher than in Australia ; on the other hand, labour is doubly efficient and the difference in management beyond the power of figures to express.

Advantages.—Those ores which have garnet for a gangue-mineral will in general be found particularly amenable to flotation processes unless a large amount of calcite is also present. Barite gangue is also separated in many instances with ease. Felspar ores are treated with excellent results. Schistose ores, which produce a large amount of slime, will also be found amenable to at least one of the processes. Copper ores, where the sulphides are

so finely disseminated as to require crushing to extreme fineness to free the sulphides from the gangue, are the special province of these processes, and they will provide the greatest scope for the future extension of this method of treatment. The ores of the Great Fitzroy mine and the Caucasus Copper company are of this type. Many of the ores where the valuable constituents are in the form of silver sulphide, accompanied by pyrite in a quartz gangue—like the ore of the San Pedro mine, Guanacevi, Mexico—give an excellent separation with high-grade concentrate and good recovery. This class of ore deserves close study in connection with these processes. An ore from Japan, containing gold apparently locked in stibnite, gave good results. This ore yielded scarcely any of its gold content by amalgamation, gravity concentration, or any chemical method. This ore required very fine grinding to free the stibnite from the quartz.

An ore from Bolivia, in which the gangue is quartz and garnet, and the valuable content in tetrahedrite, yielded 93% of the gold and silver in small tests in a high-grade concentrate.

Broken Hill.—In 1904 there was estimated to be in the dumps at Broken Hill the following by-products :

Mine.	Material.	Tons.	Assay Zn. %	Assay Pb. %	Assay Ag. oz.
Proprietary	tailing ..	2,500,000	17.0	4.0	6.0
Block 10	,, ..	520,000	22.0	6.0	9.5
	middling ..	137,000	22.5	7.5	10.5
	slime	165,000	18.0	10.0	9.0
Central	tailing ..	1,000,000	22.0	7.0	6.0
	slime	600,000	21.0	17.0	20.0
South	tailing ..	620,000	19.7	7.2	4.2
	slime	100,000	18.4	14.6	6.4
Block 14	tailing ..	250,000	16.5	7.0	6.5
British	,, ..	250,000	17.0	4.8	5.0
	slime	125,000	21.0	8.9	10.0
Junction	tailing ..	10,000	19.0	16.0	10.0
	,, ..	60,000	12.0	7.0	7.0
	slime	25,000	13.0	12.0	12.0
Junction North	tailing ..	95,000	12.4	10.0	9.0
	slime	5,000	13.0	11.0	12.0
North	tailing ..	100,000	17.0	8.0	5.0
	slime	20,000	14.0	11.0	11.0
	Total ..	6,582,000			

The annual production of zinc concentrate by flotation processes since the above estimate was made has been as follows :

	Tons.
1904	57,602
1905	103,532
1906	102,664
1907	236,251
1908	275,932
1909	373,906
1910	468,627
1911	500,000
Total estimated ..	2,118,514

The ratio of concentration on this material has been about 3.6 to 1, so that 8,000,000 tons of material has been treated. There still remains untreated sufficient material to keep the present plants going until 1919, when the accumulated tailing should be exhausted. It is evident that the 1904 estimates of tonnage available were far short of the truth. It is not probable that there will be any further great increase in the annual production of zinc concentrate at Broken Hill. It seems more probable that the pinnacle of tonnage was reached in 1910, and that the production will decrease from now on until the accumulated tailing is finished. There should be no large drop in the total tonnage produced, because the Zinc Corporation, the Amalgamated Zinc, and the Broken Hill Proprietary have reserves of tailing that will last for several years to come. One large plant last year ceased operating, but its place was taken by two smaller ones. A steady slow decrease in production may be expected, because most of these companies, during their early struggles with the vagaries of the processes, used their best material to make ends meet. They will probably make as much money out of their lower-grade material as they did out of the higher-grade material. When these immense piles are exhausted, which can be definitely predicted for 1919 or before, there will be a sudden drop in the zinc production of Broken Hill, which should considerably disturb the world's zinc market. The present production of Broken Hill zinc represents just about 20% of the total world's production. It is a remarkable fact that this enormous increase in the production of a district, which seven

years ago produced practically no zinc, has caused very little disturbance of the price. This was due to the fact that the high-grade Broken Hill zinc concentrate took the place of low-grade ores from many places in the world, outside of the United States, and these latter low-grade mines simply ceased production because the low-grade material could not compete with the high-grade at the same metal price.

The material treated by these processes at Broken Hill is of comparatively high grade, averaging at present close to 18% zinc, 6% lead, and 7.5oz. silver per long ton. In spite of these good assays, the profits are not fabulous. After charging working cost, royalty to process owners, smelters' charges, and management, there is left on an average close to 12s. per ton treated. In the case of some of the companies this is further decreased by the prices paid to the mining companies for the tailing. The average price for all the tailing and slime sold by the mining companies to the treatment companies averages about 6s. per ton, leaving on an average not over 6s. per ton profit to the treatment companies when zinc is £23 per ton. These are not the actual results of any one company, but are a fair average of the whole. Some of the companies increase this profit in favourable cases by anything up to 4s. per ton by the re-treatment of the flotation-concentrate, by means of which re-treatment a good lead concentrate is taken out of the flotation-concentrate. This lead concentrate represents about 50% of the lead in the flotation-concentrate. These figures mean that if the price of zinc dropped to £20 per ton the flotation plants would have to close down, or else reduce the working cost or economize in some other quarter.

The present selling contracts to the German zinc smelters represent a handsome profit to the latter. It seems certain that every ton of concentrate, which mostly goes to Germany, represents a clear profit to the Germans of at least 40s. per ton of concentrate or 11s. per ton of the original material. From the standpoint of the treatment company, this seems a rather liberal share of profit to the zinc smelter, and it speaks well for the acumen of the Germans that they tied up this large production under long contracts.

Some of the contracts under which this concentrate is sold are represented by the following equations :

(1.) Payment on board cars at Broken Hill =

$(Zn-8)\ (P-5\%)+(Pb-8.5)\ (1s.\ 3d.)+(Ag-5oz.)\ (P'/2)—R$

Where Zn is percentage assay in zinc.

,, Pb ,, ,, lead.

,, Ag ounces per ton of silver.

,, P is average price of zinc over six months following delivery.

,, P′ is average price of silver over six months following delivery.

,, R is a smelting and freight charge, which is £5 when the price of spelter is £17 10s., and increases 3s. per ton for each £1 increase in the average price, and decreases 3s. per ton for each £1 decrease in the average price.

There is a penalty of 1s. 3d. per unit for every unit of lead under 8%, but the lead penalty is never to exceed the payment for silver.

(2.) Payment on board cars at Broken Hill =

$(Zn-8)\ (P-5\%)+(Pb-8)\ (1s.)+(Ag-5oz.)\ (P'/2)—R$

Where Zn is percentage assay in zinc.

,, Pb ,, ,, lead.

,, Ag ounces per ton of silver.

,, P is average price of zinc during six months of delivery.

,, P′ is average price of silver during six months of delivery.

,, R is a smelting and freight charge which is £5 17s. 6d. with spelter at £23, and increases 2s. 6d. per ton for each £1 increase in the average price, and decreases 2s. 6d. per ton for each £1 decrease in the average price.

There is a lead penalty of 1s. 6d. per unit for each unit under 5%.

ROYALTIES.—The average royalty charged by the process owners for the use of these flotation processes is one shilling per ton of ore treated. This is very high royalty as measured by others with which miners and metallurgists are familiar. It is conceded that the inventor deserves compensation for his ingenuity, but 1s. per ton is about four times as large a royalty as the mine manager would expect. Large royalties have the disadvantage that they place a premium on infringement, and for this reason alone are,

from the standpoint of the process owner, not good business. The combined capital of all the companies owning flotation processes is close to £1,000,000. This means that 20,000,000 tons of ore will have to be treated and pay royalty of 1s. per ton before the capital is returned. These companies have been in existence now about seven years, and if we consider the investment ought to earn 10%, then the processes should have treated to date, besides the above tonnage, 14,000,000 tons more, making a total which should have been treated to date 38,000,000 tons. They are still about 30,000,000 tons behind the game. This does not mean anything particular, except that as a class these process companies were considerably over-capitalized, and have also wasted their money, both revenue and capital, on expensive litigation.

WORKING COST.—Figures on cost and recovery, owing to entirely unnecessary secrecy on the part of some of the companies, are not to be secured in the ordinary manner. But there are few secrets* which do not yield to the cruel analysis of the mathematical equation, assisted by scraps of evidence which can be collected in the broad light of day. By these means and the published returns of those who are proud of their work, a fairly correct summary of the whole position can be made as to the treatment of Broken Hill zinkiferous tailing. The following is a general average of all the processes :

	s.	d.
Tramming to plant		6
Re-crushing	1	8
Flotation treatment	3	7
Handling concentrate		6
Handling residue		6
Re-treatment of concentrate ..	1	6
Royalty	1	0
Total	9	3

Of these figures the only one which needs discussion here is the general average of 3s. 7d. for the flotation treatment, and it will be interesting to compare the cost of different processes in this particular. These figures do not exactly correspond to those given in previous chapters, because certain items have been reduced to a comparative basis by using one price for the respective materials used.

*_The Mining Magazine_, August, 1910, 'Percentages of Recovery.'

Item.	Potter-Delprat. s.	d.	De Bavay. s.	d.	Elmore. s.	d.	Minerals Separation. s.	d.
Power ..		.90		1.50		1.34		1.74
Acid	1	3.00		8.00	1	0.90	1	0.15
Oil				6.00		6.00		6.00
Supplies ..		6.00		6.00		6.87		5.50
Labour ..		2.00	1	0.00		5.68		2.22
Fuel for heating		6.00						5.42
Assays ..		.30		.30		.38		.30
Water ..		1.50		1.50		1.99		1.50
General expense		8.72		8.72		8.72		8.72
Total	3	4.42	3	8.02	3	7.88	3	7.55

Power.—In the Potter-Delprat process this figure is for pumping and circulating the acid liquor. As a power charge it is confused to some extent with upkeep of pumps, which is a greater item than it would be if the pumps were handling only water. In the De Bavay the power charge includes the washing of the pulp, mixing with the oil, and elevation of the pulp. In the Elmore the charge includes mixing, the vacuum, and elevation. In the Minerals Separation it includes mixing and aeration by means of violent agitation, and also elevation of the pulp, and in this process the power charge will always be one of the largest. In theory it accomplishes the act of flotation by the direct expenditure of energy.

Acid.—The acid cost is obtained by an indirect method. In the Government reports the tons of acid produced in the year are given, and it has been assumed that it was all used in some of the flotation processes. It is possible that some of the De Bavay or Elmore acid should be charged to Minerals Separation. The error, however, is not large.

Oil.—The Potter-Delprat presumably uses no oil, and this, together with the low labour cost, gives that process a definite lead over all the others. The De Bavay uses a comparatively expensive oil in considerable quantity. The Elmore uses a cheap oil in comparatively large quantity, and Minerals Separation uses a very expensive oil in small quantity.

Supplies.—The item for supplies other than oil, acid, fuel, and water will be just about the same in all the plants. The Potter-

Delprat has a considerable bill for renewal of boxes ; the De Bavay extends over a wide area ; the Elmore has the most machinery ; and the Minerals Separation must renew the mixing devices.

LABOUR.—Considering the simplicity of operations, this cost is excessive when measured by general practice, the general inefficiency of Broken Hill labour, coupled with its high cost, being responsible. The figures given are thought to be reasonably correct for each of the processes, but may contain some error. The Potter-Delprat takes the least number of men to operate ; the De Bavay covers a wide area and requires close attention ; and the Elmore requires more men than either the Potter-Delprat or Minerals Separation.

FUEL FOR HEATING.—The Potter-Delprat process is conducted at a higher temperature than any of the others. The De Bavay operates at the normal temperature, as does the Elmore also generally. The Minerals Separation uses 60° to 70° C.

ASSAYS.—This is a comparative charge, and should not differ in any of the processes ; some of them may have no assay charge.

WATER.—Water at Broken Hill costs 5s. per 1,000 gallons. The loss per ton by unreclaimed water in the residue will be almost identical in each case, as the methods of reclaiming water are similar, being by way of settlement first in tanks until sufficiently dry to travel on a belt or be handled in trucks. The losses by leakage and evaporation should be about the same in each case.

GENERAL EXPENSE.—This charge, being accurately known in one case, is assessed for purposes of comparison to all of the processes at the same figure. There is really a big difference, but this difference is not inherent in the process ; some of the plants are managed efficiently for half the cost of the bad management in others.

CONCLUSIONS.—There is not much to choose between the working costs of the four. The advantage which any one process may have over the others lies in the comparative recovery, grade of concentrate, cost of plant, and general applicability. The working cost of treating copper ores will be about 25% less than the figures given, because less concentrate is handled and less acid in general is used. In spite of the fact that the general average of treatment cost is in the neighbourhood of 4s. per ton in the plants studied, I think that under the efficient management that is given to American mines, and with an efficiently designed plant and properly chosen process, a working cost of 2s. per ton is easily

within reach. The royalty of 1s. per ton does not seem imminently reducible.

As a demonstration of the utility of the invention, we may say, then, that it has already added to the world's wealth nearly 1,000,000 tons of spelter, 100,000 tons of lead, 20,000,000 oz. of silver, and 5,000 tons of copper ; and at the present rate is adding 200,000 tons of spelter, 20,000 tons of lead, 5,000,000 oz. of silver, and 1,000 tons of copper yearly.

CHAPTER XII.

BIBLIOGRAPHY.

The literature of the flotation process is about 10 years old. The published articles have not been many, and what has been published has not been particularly informing. There has been an effective effort on the part of the companies owning the patents to suppress details because of a groundless fear of competition and of new inventions not owned by themselves. The one exception to this line of policy has been the Elmore companies, who have from the very first been quite open in their communications to the public. Whether the other process companies have been wise from a money-making standpoint is their affair. There is no doubt, however, that the development of the art has been seriously delayed, and the industry is thereby the loser. No papers deserving special mention have been published. The few descriptions of plant and processes that exist are of about the same merit. Most of the important papers on the theory of capillary action, surface tension, and adhesion have also been included in the bibliography. Of these the article in the *Encyclopedia Britannica* is the most important.

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p. 90, Broken Hill prospects, 1 col.
p. 115, Murex process, 10 lines.
p. 155, Zinc Corporation, $\frac{1}{4}$ col.
p. 182, Broken Hill Proprietary, $\frac{1}{2}$ col.
p. 183, De Bavay, output, one-fifth col.
p. 210, Broken Hill Proprietary, $\frac{1}{3}$ col.
p. 210, Broken Hill South, $\frac{1}{3}$ col.
p. 226, British zinc flotation plant, 20 lines.
p. 227, Murex Magnetic, 20 lines.
p. 233, Additions to plant, illustrated, 2 pages.
p. 250, Central Zinc company, $\frac{1}{4}$ col.
p. 251, Sulphide Corporation, 10 lines.
p. 252, Litigation, De Bavay, one-fifth col.
p. 264, Potter's Sulphide Ore Treatment Co., one-fifth col.
p. 277, Litigation, 20 lines.
p. 278, Murex process, 8 lines.
p. 289, Broken Hill Proprietary Co., $\frac{1}{2}$ col.
p. 290, De Bavay, one-fifth col.
p. 314, Eucalyptus oil, $\frac{1}{3}$ col.
p. 315, Broken Hill, $\frac{1}{6}$ col.
p. 330, British Broken Hill, 10 lines.
p. 333, Oil flotation at Broken Hill, $\frac{2}{3}$ col.
p. 337, Murex Magnetic plant, 20 lines.
p. 383, Zinc plant, British mine, 20 lines.
p. 393, Great Fitzroy, $\frac{1}{2}$ col.
p. 393, Broken Hill Proprietary, $\frac{1}{2}$ col.
p. 415, Commonwealth Oil Corporation, 2 col.
p. 418, Broken Hill prospects, 1 col.
p. 419, Returns, $\frac{1}{3}$ col.
p. 433, Minerals Separation American Syndicate, 8 lines.
p. 444, Broken Hill prospects, 1 col.
p. 460, ditto, $1\frac{1}{2}$ col.
p. 494, ditto, 1 col.
p. 517, Block 10, $\frac{1}{3}$ col.
p. 517, Amalgamated Zinc, $\frac{1}{4}$ col.
p. 517, Zinc Corporation, $\frac{1}{4}$ col.
p. 538, Murex, 20 lines.
p. 557, ditto, 3 lines.
p. 561, ditto, $\frac{1}{2}$ col.
p. 562, Process production, 2 col.
p. 488, Murex, $\frac{1}{4}$ col.
p. 488, Processes, $\frac{1}{2}$ col.
p. 612, Murex, 10 lines.
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p. 68, Production of concentrate, ½ col.
p. 116, Murex, 5 lines.
p. 117, Sulphide Corporation, ½ col.
p. 142, Minerals Separation, ½ col.
p. 159, Zinc Corporation and Amalgamated Zinc, ½ col.
p. 170, Zinc Corporation, ¼ col.
p. 181, Minerals Separation process and Zinc Corporation, 2 col.
p. 186, Murex, 12 lines.
p. 195, Broken Hill Proprietary and Amalgamated Zinc, 1½ col.
p. 219, Minerals Separation process, ¼ col.; Broken Hill Proprietary, 1 col.
p. 220, Potter process, ¼ col.
p. 244, Elmore process at the British mine, ¼ col.; start of Central slime-plant in March, 10 lines.
p. 245, Zinc Corporation, ¼ col.
p. 270, Minerals Separation process, 10 lines.
p. 284, Murex process, 20 lines.
p. 297, Amalgamated Zinc, ¼ col.
p. 311, Litigation, Potter *v.* Ballot, ¼ col.
p. 323, Broken Hill Proprietary, ¼ col.
p. 340, Minerals Separation process at Junction North, ¼ col.
p. 343, 'Flotation of Minerals,' by Kenneth A. Mickle, 2½ col.
p. 365, Minerals Separation process at Zinc Corporation, ¼ col.
p. 366, Elmore process at the British mine.
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p. 371, Production of zinc concentrate in 1910, 1 col.
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p. 437, Murex process, ½ col.
p. 443, Sulphide Corporation, 20 lines.
p. 459, Murex, 3 lines.
p. 462, Zinc Corporation, Elmore, and Ballot, ½ col.
p. 469, Zinc Corporation, ¼ col.
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p. 488, Murex, 10 lines; Ballot, 15 lines.
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p. 544, Zinc concentrates, 12 lines.
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p. 54, Litigation, ½ col.
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p. 141, Reports of companies, 1 col.
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p. 219, Amalgamated Zinc, 10 lines.
p. 243, Potter Sulphide Co., 20 lines.
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p. 243, Broken Hill Proprietary, ¼ col.
p. 262, New slime flotation process at Broken Hill Proprietary, 20 lines.
p. 269, Working results for month, 1 col.
p. 287, Amalgamated Zinc, ½ col.
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p. 293, Amalgamated Zinc, 2 pp.
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INDEX.

PAGE

Acid—
Addition 132
,, Hyde 37
,, in tests 67
,, amount 90
Average price 90
Avoidance of waste 135
Charged extra 91
Cheap—Elmore 101
Coagulation without 79
Cost—Potter 91
De Bavay adopts 92
Delprat *v.* Potter 42, 43
Economics 165
Effect on hysteresis 57
,, recovery 70
Elmore claim invalid 47
Excess-acid problem 79
Gas producer—Elmore 102
Gasification by agitation 78
Hyde uses 16
Hydrochloric—formation of 95
Increases selective action 4
,, adhesiveness 53
Introduction temperature 82
Its function 79
Limiting amount 35
Nitric acid 26
Measuring for tests 63
Methyl orange test 135
Non-acid possibilities 79
Oleic acid 63, 68
Priority of idea 46
Proportion of De Bavay 92
,, Elmore 101
,, Hoover apparatus 113
,, Potter 8, 24, 25
Result of addition 55
Robson & Crowder reject 22
Soluble in water 86
Solution De Bavay 92
,, Potter 83
Sulphuric acid proportion 70
Sutton uses 21
Tin recovery unaffected 103
Unused—Early De Bavay 92
Use infringes Elmore 47
Acid-Flotation Process—
Common salt used 30
Defect in 12
Delprat's claims 42
First disclosure 27
Potter's claims 42
Potter illustration 81
Acidity—
In old water 119
Acid Salt-Cake, see Salt-cake.
Active Forces, see Forces.
Adhesion 52
Adhesiveness unexplained 53
Attraction 53
Aversion or affinity 54
Carbon-dioxide and sulphides 80
Enhancement—Potter 80, 85
Enumeration of forces 54
Film of air flotation 55
Flotation considered 52

PAGE

Adhesion—
Gas adhesion 53
Gas-bubble 54
Increase by acidulation 53
Increase by sulphur chloride 41
Liquid adhesion 53
Metallic sulphides 53
Molecular phenomenon 52
Natural tendency 55
,, ,, enhanced 55
Not limited to solids 53
Of gas-films 80
Oil-gas adhesiveness 53
Preferential 60
Promoted by aeration 95
Selective organic compounds 80
Solid and liquid 57
Solid and gas 57
Unbalanced liquid stresses 53
Without oil or acid 79
Adhesiveness 57
Gas and liquid 57
Solid and gas 57
Adsorption 54
Advantages of Flotation—
Economics of 159
Aeration, see Air.
Affinity—
Obscure law of 47
Agent, see also Fat, Oil, Acid—
Soluble frothing 59
Transporting 58
Agitation—
Advantage—Discovery—Everson 4
Aid to coagulation 89
Agitators—speed 122, 123
,, not needed 123
A.Z. Agitator—illustration 93
Centrifugal effect—Hoover app. 116
Deleterious substances 78
Description froth process 10
Elmore mixer 100
,, slow-moving 101
Everson process 20
Further agitation—Hoover 117
Gasification by 78
Haynes process 18
High speed—De Bavay 93
Hoover—Less subsequent 114
,, High speed 116
,, Improved process 119, 121
How performed—Elmore 98
Hyde process 16
In tests 63
Kirby 30
Minerals Separation process 10
Number of agitators 120
Object of—De Bavay 93
Occlusion of bubbles 78
On addition of oil 14
Production of bubbles 56
Pumping by agitator 116, 118
Renewal of 93
Robson & Crowder 6
Speed, in tests 67
,, of rotation 73
Sulman, Picard & Ballot 33

PAGE

Agitation—
Tests—Renewal periods 73
,, Second period 68
To break up bubbles 89
Variation tests 71
Violent agitation tests 72
,, ,, Wolf 27
Air—
Amount of 102
Blown in—Kirby substitute 30
Carbonic acid replacement 79
Compressed air—De Bavay 95
Cu. ft. in solution 102
Elmore—Scammel method 42
,, vacuum releases 102
Exclusion of 26
Further aeration—Hoover 117
Hebron process—aeration 21
Hockley's patent 21
Hoover apparatus 113
High-pressure solution 35
Klein patent.................... 23
Liberation of—Elmore 13
McCoy's patent 22
Norris' Patent application 45
Proportion of 13
Repeated aeration—De Bavay ... 95
Repeated exposure to............ 35
Robson & Crowder 22
Table—Elmore consumption 102
Volume—Elmore 102
Air, see also Gas (bubbles).
Air-Flotation, see Flotation.
Air-occlusion, see Bubbles.
Allen, H. A.—patent described........ 27
Alcohol—
Gasification with 78
Alkaline Solution 26, 28
Sanders 32
Alpimina Mining Co., Peru—
Van Meter & Boss process 8
Amalgamated Zinc, see De Bavay.
Ambitious Inventors .... iii.
Amyl Acetate—
Froth agent 120
Amyl Alcohol 59
Gasification with 78
Froth agent.................... 120
Ancient Method of Separation 1
Angle of Contact, see Contact Angles.
Angular Hysteresis, see Hysteresis.
Annual Report Dept. of Mines, see Dept. of Mines.
Antimony Sulphides—
Difficult separation—Elmore...... 103
Apparatus, see Machinery.
Aramayo, Francke & Co.—
Use Murex 15
Assays—
Br. Hill blende 111
,, tailings 111
Concentrate 110
,, Telemarken mine 107
,, Traag mine 107
Cost—Potter-Delprat 91
Dolgelly concentrate—Elmore 104
Dolgelly tailing—Elmore 104
Economics of 166
Edmundian mine................ 106
Feed tailing—Zinc Corp. 131
Final residue—Elmore 105
Final tailing—Sulitelma 110
Lead—De Bavay................ 97
,, Proprietary 91
Ramsley concentrate—Elmore 104
Silver—Proprietary 91
,, De Bavay 97
Tailings 162

Assays—
Traag mine, Norway 107
Telemarken mine................ 107
Wilfley lead conc. 105
,, zinc conc. 105
Zinc Corp. concentrate 104
,, material.............. 104
Zinc—De Bavay 97
Zinc—Proprietary 91
Assay of Concentrates, see also Concentrates.
Assaying, see Working Costs.
Assistance of Others, Indebtedness to.. iii.
Atmospheric Oxidation, see Oxidation.
Atmospheric Pressure 27
Attraction—
Between liquid and vessel 53
Avino Mines—
Refractory ore 156

Baker City, Oregon—
Everson first tried 5
Ballot 3, 17, 111
Elmore, action against 44
Minerals Separation formed 9
Barite—
Difficult separation—Elmore...... 103
Base Metals, see also Copper, Zinc, Lead, etc.—
Combined with sulphur 1
Metallurgy 2
Methods of dressing ore 1
Bibliography........................ 168
Acknowledgments .... iii.
Bingham Canyon Ore 157
Bisulphate of Alkali Patent 29
Black Jack—
Br. Hill blende 111
Blende, see Sulphide.
Block 14 Mine, Br. Hill—
Used Potter 9
Blount, Bertram—
On sulphide particles 54
Boss, Martin P. 3
See also Van Meter & Boss process.
Boston Consolidated Co.—
Used Elmore 7
Bornite—
Ramsley Mine, Devonshire 104
Telemarken mine 107
Troublesome.................... 157
Bradford, Hezekiah 3
Patent described 19
Process outlined 4
Similarity to De Bavay 92
Broken Hill Proprietary—
Illustration of plant 88
Potter costs analysed 90
Uses Potter process 9, 81
Uses Delprat process 87
Broken Hill Proprietary Block 14—
Used Potter process 86
Broken Hill South Blocks—
Amalgamation with Zinc Corp..... 16
Broken Hill Zinkiferous Material, see Zinc.
Brown, R. Gilman—
Aberration—Elmore process 79
Bubbles (see also Gas) 55
Action explained 56
Air—by agitation 56
Air—occlusion problem 79
And particle—radii 56
Breaking of—Potter 86
,, ... 12, 28
Carbonic acid gas 56
Surface aspects 55
Form froth 56

PAGE

Bubbles (see also Gas)—
Froth—Hoover app. 114
Froth prevents breaking of 86
Increase effective surface 58
Ineffective attachment 89
Loss of—Potter 84
Mechanical breaking up of 89
Milky appearance 78
Occlusion by agitation 78
Potter—Carbon dioxide 82
Relative diameters 56
Released by vacuum 56
Size of bubbles 55, 58
Sulphides uniform action 55
Super-atmospheric pressure 56
Their radius 55
Too rapid growth 89
Various kinds produced 56
Vacuum formation 98
With agitation—test 78
,, alcohol 78
,, amyl alcohol 78
,, camphor 78
,, essential oils 78
,, kerosene 78
,, oleic acid 78
Buddle, see Machinery.
Buoy-Stock 5
Rubbing movement 21
Heat and vacuum 21
Burn, Alfred K.—
Indebtedness to .... iii.
Butters, Charles—
Purchased Elmore (old) process .. 7
Camphor 59
Gasification with 78
Calcite—
Broken Hill gangue 111
B.H. Proprietary tailing 81
Contained in slime 89
Froment process 9
Importance to flotation 81
Potter test 75
Producing gas—Elmore 102
Calcium carbonate 62
An essential—addition of 155
Calibration 137
California Fuel Oil, see Oil.
Capacity—
Amalgamated Zinc mill 96
British plant 89
Concentrates—Potter 85
Delprat—Proprietary 87
Elmore unit 100, 101
Estimated daily—Minerals Sep. .. 120
Flotation vats—Potter 85
Gillies plant 90
Hoover apparatus 114
Mill *v.* Units 105
Minerals Sep.—Saxberget 110
North plant—De Bavay 95
Of zinc-tanks 141
Sulitelma concentration mill 110
Cape Copper Co.—
Used Elmore 7
Capillary Action 49
Carbon—
Separating from impurities 30
Carbon Dioxide, see also Gas 60
Carbonate—
Absence and addition 76
Acid action upon............... 81
Acid and bubbles 56
Addition by De Bavay 35
Excess of, detrimental 155
Film of, removal 14, 31
Importance to flotation 81
Potter—acid action............. 82

PAGE

Carbonate—
Potter test 75
Tests—proportion 70
Carbonate, Complex—
Broken Hill gangue 111
Carbonate, Iron—
B.H. Proprietary tailing 81
Carbonate Minerals—
Limitation of flotation 155
Carbonate Ores—
Is flotation feasible ? 79
Carbonate of Ammonia—
Soaking ore in—De Bavay .. 14, 31
Carbonic Acid Gas—
Passed into wet ore—De Bavay 14, 31
Potter-Delprat 59
Replacement by air 79
Cattermole, Arthur Edward 3
Cattermole Process 3, 17
Abandoned by Min. Sep. 124
Description of 10, 111
Offered Elmore and Webster...... 44
Patent described...... 25, 26, 29, 30
Purchased by Minerals Sep. 9
Cattermole, Sulman & Picard—
Patent described 28, 30
Central Plant, see New Central Plant.
Central Mine, Broken Hill—
Used Min. Sep. process 10
Centrifugal Effect—
Of agitation 116
Chalcocite—
Ramsley Mine, Devonshire 104
Troublesome 157
Chalcopyrite 62
Difficult separation—Elmore...... 103
Edmundian mine............... 106
Garpensberg Mine, Sweden....... 107
Ramsley Mine, Devonshire....... 104
Sulitelma—Friability 108
,, Mine 108
Telemarken Mine............... 107
Chapman, George A........... 3, 17, 111
Indebtedness to .... iii.
Patent described 35
Chemical Reaction Unlikely.......... 60
Chlorine Gas, see Gas.
Cinnabar—
Readily concentrated—Elmore ... 103
Clear solution, see Acid.
Cleavage Plane 57
Coagulation 60
Agitation an aid 89
Coagules 61
Example of butter 61
Flocculent masses.............. 60
For slime treatment............ 60
Hyde process.................. 16
Illustration, verbal 60
Manifestation of adhesion 61
Potter pulp 85
R. Storm on 60
Rescues slime 61
Rolling-motion stirring 61
Salts, beneficial effect........... 119
Soap addition 60
Sulman & Picard............... 30
Without acid 79
,, oil 79
Coalescence, see Coagulation.
Cohesion 41, 52, 54
Combinations—
Economics 158
Flotation and other treatments.... 158
Commercial Aspect—
Application 6
Elmore (Old process) 6, 23
Gillies process—failure 14

PAGE

Commercial Effectiveness 58
Commercial Recovery—
  Potter's advantage 85
Common Salt Process, see Delprat.
Compactness—
  Hoover app. (New) 118
Concentration, see Separation, Water Concentration.
Concentrates—
  Assay of—Delprat 88
    ,, Dolgelly-Elmore 104
    ,, Ramsley-Elmore 104
    ,, Telemarken mine 107
    ,, Traag mine 107
    ,, Zinc Corp. 104
  Capacity—Hoover app. 114
  Crushing, sizing—Elmore 101
  De Bavay best produced 95
  Delprat, production of 88
  De-oiling by heat 104
  Discharge—Elmore 99
  Drying—Zinc Corp. 104
  Edmundian mine—assay 106
  Elmore tonnage—lead 105
    ,, ,, zinc 105
  Entrapping concentrate 3
  Floating concentrate—illustration . 83
  Gillies, production of 90
  Gummosity of 80
  Gummy—Potter 86
  High-grade conc. and recovery .. 11, 38
    ,, Hadeland mine 107
  Hyde—Low-grade to high 16
  Lead concentration 137
  Lead—De Bavay 97
  Lead and zinc—Zinc Corp. 140
    ,, market 125
    ,, concentration 125
  Lead-zinc-silver—Saxberget 110
  Ore yield 16% 102
  Potter capacity 85
  Production—Proprietary 91
  Ratio of 161
  Ratio of—Proprietary 91
  Ratio of supply—De Bavay 97
  Re-treatment by burning 13
    ,, —Potter 86
  Re-flotation 134, 137
    ,, calibration 137
  Softness of material—Dolgelly 104
  Subsequent treatment 120
  Sulitelma 110
  Tin—Elmore 103
  Total—De Bavay 97
  Washing—Potter 84
  Wilfley lead concentrate 105
  Wilfley re-concentration.......... 105
  Wilfley treatment 105
  Wilfley zinc concentrate 105
  Wolf's low-grade—high extrac. 12, 27
  Zinc-concentrate 137
  Zinc—De Bavay 97
Concentration by Flotation 2
Contact Angle 5
  And meniscus.................. 79
  Variation 57
  Method of measuring 57
  Mutual-solid-liquid-gas 57
  Problem of 79
  Sulman on 57
Content, see Metal Content.
Cooling, see Heat.
Copper—
  Ore treatment—Dick 36, 37
  Dolgelly ore 104
  Garpensberg mine 107
  Sulitelma mine........... 108, 110
  Telemarken mine............... 107

Copper—
  Copper Finely Disseminated 2
  Special province of flotation...... 160
Copper Pyrite, see Chalcopyrite.
Copper Sulphides—
  Difficult separation—Elmore...... 103
  In tin ore 103
Copperas (Iron sulphate)—
  Hyde process 16
Cornwall Tin Ore, see Tin.
Cost, see also Working cost—
  Elmore unit 100
  Potter plant 86
  Repairs—Potter 85
Crilly, Thomas F.—
  Financed Everson 5
Crilly & Everson Process, see Everson.
Crowder.......................... 3
Crushing, see also Grinding—
  Brightens sulphides.............. 112
  B.H. tailings 112
  Elmore—Zinc Corp. 105
  Fine crushing—Minerals Sep...... 112
  Slime production—Minerals Sep. .. 112
Curle, J. H.—
  Formation of Minerals Sep. 9
Cylinder Oil, see Oil.

Darling, James D. 3
  Patent described 30
De Bavay, A. J. F.................. 3
  Adopts oil and acid 92
  Amalgamation Minerals Separation 92
  Amalgamated Zinc buys 14, 96
  Amalgamated Zinc amalgamates with Min. Sep. 17
  Australian rights 95
  Basic principle 76
  Clean sandy feed 92
  Composition of oil 93
  Clear statements not published ... 14
  Cream of tailings 96
  Drawing off solution 93
  Experimental work 95
  Film of sulphides 92
  Finality reached 92
  First used North mine 92
  Flotation cones 93
  Full description of process 92
  High-speed agitation 93
  Installed Block 10 14
    ,, B.H. North mine 14
  Later stages described........... 92
  Metallic scum 93
  Mixing device 92
  North mine plant 95
  Object of agitation 93
  Oiling tailing 93
  Oiling vat 93
  Patent described 31, 32
  Process described 13
  Proportion of acid 92
  Purely surface-tension........... 92
  Recovery.................... 96, 97
  Re-treatment plant 96
  Renewal of agitation 93
  Repeated washings 93
  Similarity to Bradford 92
  Slime discarded 92
  Tables of recovery 95
  Tailing de-slimed 92
  Tests 76
  Tonnage treated 97
  Uses surface film 58
  Vannering scum 93
De Bavay Treatment Co.—
  World rights.................... 14

PAGE

De Bavay Sulphide Process Company—
  Owners in Australia 92
De Bavay v. Macquisten 42
De-Leading Section 137
Deleterious Substances 78, 79
  Elmore process aberration 79
  Flour 79
  Glue 79
  Ox-gall 79
  Starch 79
  Tannin 79
De-Oiling, see Oil.
Delprat, Guillaume D. 3, 8, 80
  His work 80
  Application overcoming invalidity 45
  Bi-sulphate alkali patent 29
  Common salt process 30
  Manager B.H. Propy. 87
  Patent described 25, 26, 27
  Plant re-modelled 88
  Potter's Australian rights 80
  Used by Proprietary 87
Delprat Pan—
  Introduction Block 14 86
Density of Solution—
  Avoidance of 135, 136
  Remedy for 136
Department of Mines N.S.W.—
  First mention flotation 123
De-Sliming, see also Working Costs, Slime—
  De Bavay 92
Deterioration of Belts 139
Detrimental Conditions—
  Through weathering 14
Detrimental Effect of Salts, see Salts.
Development of Processes—
  By Minerals Sep. 111
De-Watering, see Water.
Dick, Frank Burnett—
  Patent described 36, 37
Differential Flotation, see Flotation.
Dimensions of Units—
  Minerals Separation 120
Discovery of New Methods—
  Spur to 1
Dodé, Edward 3
  Patent described 20
Dolcoath, Cornwall—
  Elmore process used 103
Dolgelly Mine, N. Wales—
  Elmore plant used 104
Douglas, James—
  Secrecy in commerce 40
Dumps—
  Remov[illegible] Corp. 130
Duplicat[illegible]ention—
  Pre[illegible]on of .... iii.
Dyne—
  Metric expression 50

Economic Aspect, see Commercial Aspect.
Economics of Flotation .... 154 to 167
  Acid 165
  Advantages 159
  Assays 166
  Combinations of processes 158
  Conclusions 166
  Fuel 166
  General Expenses 166
  Labour 166
  Limitations of process 154
  Magnitude of process 159
  Oil 165
  Power 165
  Royalties 163
  Supplies 165
  Sulphide separation 157

PAG

Economics of Flotation—
  Slime 158
  Water 166
Edmundian copper mine, S. Africa—
  Chalcopyrite 106
  Desc. of plant 106
  Elmore process used 106
  Recovery 106
Effective Surface, see Surface.
Effervescence—
  Everson 6
  Hebron process recommends 21
Electrolysis of Water 30
Elmore, Alexander Stanley—
  Patents described 23, 24, 26, 30, 33
Elmore, Francis Edward—
  Patents described 22, 23, 30, 31, 32
Elmore Brothers 3
  Elmore (Old Process) outlined 6
Elmore Vacuum Process 8
  Abandoned Zinc Corp. 106
  Aberration described 79
  Absence of vibration 101
  Acidulation claim invalid 47
  Action against Webster, Ballot & Hay 44
  Air per ton 102
  Alleges infringement Min. Sep. .. 44
  Ambiguity of patents 47
  Annular space 100
  Application of process 102
  Basic principles 98
  Breakages almost unknown 103
  Clean tailings 103
  Conical separating chamber 100
  Crushing 105
  Darling's decision quashed 44
  Description of process 13, 98
  Discharge continuous, automatic .. 100
  Distribution total conc. 106
  Dolgelly Mine, N. Wales 104
  Durability of plant 103
  Edmundian mine 106
  Essential differences 47
  Excellent mechanical design 103
  Exhaustive trials made 105
  Expansiveness or contractiveness .. 47
  Explanation of process 98
  Extraction—Dolcoath mine 104
  Feed tonnage—Zinc Corp. 105
  Final lead conc. 106
  Flotation—Zinc Corp. 105
  Flow Sheet—Telemarken 109
  ,, Zinc Corp. 106
  ,, Garpensberg Mine .. 107
  Illustration section 99
  ,, machine 100
  "Mining Journal" article 104
  Inapplicable all ores 103
  Increase of surface 58
  Ingenuity of 98
  Justice Buckley's definition 41
  Justice Neville's definition 46
  Lord Atkinson's definition 47
  Lord Chancellor's criticism 47
  No delicate adjustments 103
  No expensive foundations 101
  No sizing pulp 101
  Non-suited by Darling 44
  Observation windows 100
  Oil and acid introduction 98
  One unit v. mill 105
  Other installations 110
  Percentage distribution—Feed 106
  Possible differential flotation 102
  Priority valid 47
  Proportion of air 102

PAGE

Elmore Vacuum Process—
Pulp introduction 98
Refractory ore success 103
Re-grinding—Zinc Corp. 104
Residue—percentage distribution.. 106
,, Zinc Corp. 105
Re-treatment on Wilfley's 105
Revolving drum 6, 23
Satisfactory extrac.—Hadeland .. 107
,, results—Dolcoath 103
Separable compounds—list 103
Separates diamonds 24
Sizing—Zinc Corp. 105
Solid construction 103
Subtlety of patents 47
Success at Saxberget 110
Sulitelma 107
Syphon arrangement 99
Table of tonnages 105
Tailing—Direct-treatment 104
Telemarken mine—Norway.. 107, 109
Test 77
Thickening tanks................ 109
Traag mrne—Ceased working 107
Two yea s continual use 105
Used at A vino mine, Mexico 13
,, Bt. B. Hill Propy. 13
,, Caucasus copper mine ... 13
,, Cobar gold mines, N.S.W. 13
,, Dolcoath............ 13, 103
,, Dolgelly, Gt. Britain 13
,, Edmundian mine, Africa 13, 106
,, Garpensberg Mine, Scandinavia 13
,, Hadeland, Scandinavia 13, 107
,, Namaqua copper........ 13
,, Pinnacles mine, N.S.W. .. 13
,, Ramsley mine 13, 104
,, Saxberget, Scandinavia 13, 110
,, Sulitelma, Norway 13
,, Telemarken mine 13
,, Traag mine, Norway.. 13, 107
,, Zinc Corp. 13, 104
Wear small 103
Webster's opinion on 44
Where other methods impossible .. 103
Widely experimented 103
Working cost 101
Zinc conc. tonnage 105
Zinc Corp. adopts and abandons ... 16
Elmore *v.* Minerals Separation—
Case described—Appeal 46, 47
German patent 45
Elmore *v.* Sulphide Corporation Ltd.—
Appeal pending 48
Case described 48
Elmore *v.* Van Meter—
Case summarized 41
Electric Light, see Working Costs.
Electric Power, see Working Costs.
Emulsification 7
Alkaline agents 26
Engineers—
Point of departure for .... iii.
Enhanced Tendency, see Adhesion.
Essential Oil—
Eucalyptus Amygdalena 60, 71
Froth producer 120
Test 71
Evaporation—
Loss of water 139
Everson, Carrie J. 3
Analagous to Haynes' 20
Patent described 20
Tardy justice to 5
Expenses, see Working Cost.
Experimental Account, see Working Costs.

PAGE

Experimental Work, see Tests.
Extraction see also Recovery—
Elmore—Dolcoath tin 104
Elmore mill *v.* unit 105
Satisfactory—Elmore—Hadeland.. 107

Fat, see Oil.
Feed, see Tailing.
Felspathic Gangue, see Gangue.
Filling—
Gangue utilised—Potter.......... 85
Film, see also Oil, Pulp—
Air-film flotation 55
,, De Bavay 95
Film and bubble 32
Film of air 29
Film of gases 53
Gas and oil—Potter 85
Of sulphides—De Bavay 92
Of carbonate—De Bavay 14, 31
Scum—De Bavay 14
Surface film 58
Without acid or oil 79
Filter Press 26
Final Residue, see Residue.
Financial Papers—
Indebtedness to .... iii.
Fineness of Crushing, see also Crushing—
Requisite fineness—Minerals Sep... 112
Fineness of Material, see Material.
Fire Account, see Working Costs.
Float Gold, see Gold.
Floating Concentrate, see Concentrate.
Flocculent Masses, see Coagulation.
Floor Space—
Saving—Hoover apparatus.. 115, 118
Flotation 2
Accidental discovery at Denver.... 5
Air—generally used 80
Air per ton—Elmore 102
Air *v.* oil-flotation 42
Addition of acid 55
,, oil 55
Analysis of principles 55
Applicability 154
Bad reagents problem 79
Carbonate flotation feasible(?) 79
Chronological discussion difficult (?).
Differential flotation—Elmore 102
Elmore's oil-flotation 46
,, vacuum 98
Elmore—Zinc Corp. 105
Gas, Selective action 3
Goyder's tests 75
Gravity 57
Heavy substances 2
Ideal ore 155
Knowledge of not 2
Largest plant—De Bavay 14
Lines of progress 155
Limitation..1st 154
,, 2nd 155
,, 3rd 156
,, 4th 156
Main principles enumerated 54
Minerals Sep. air-flotation 46
Non-acid process (?) 79
Novelty of earlier phases 2
Oil, Selective action 3
Potter—gas process 80
,, How accomplished 80
Repeated use of water 119
Restricted range 154
Salts' detrimental effect 119
Separation of oranges 154
Simplest case of 55
Speed of—Potter 85
Stages of development 3

PAGE

Flotation—
Sulman's Hysteresis discovery 57
Sure expedient of metallurgist 2
Tests 62
What is flotation ? 60
Wide field 2
With film of air 55
Without oil, acid 79
Wood separated from rubber 154
Flotation Agent—
Turpentine 37
Flour—
Deleterious to frothing 79
Flow-Sheet—
Block 14 87
Elmore—Zinc Corp. 106
New Central plant—Min. Sep. 126
Potter-Delprat 83
Telemarken mine—Elmore 109
Fluorite—
Contaminates concentrate 156
Fluoride—
Added to pulp 35
Foam, see Froth.
Forces—
Act continuously 58
Enumeration of 57
Unit force 58
Friction—
De Bavay—carbonate film 14, 31
Friction Head—
Hoover app. (new).......... 117, 118
Froment, Alcide 9, 17, 111
Addition of calcite 9
Patent described 24
Purchase by Webster 44
Froth, see also Film—
Adherence of oil 60
Agent added continually 60
Alcohol 36
Aromatic hydroxides—phenol 36
Characteristic—Minerals Sep. 92
,, Potter-Delprat ... 92
,, Elmore 92
Coagulation 61
Constituents 60
Deleterious substances 78
Dense froth—Potter 83
,, Hoover app. 114
Disadvantage of skimming 73
Elmore's vacuum 98
Emergence—Hoover app. 114
Eucalyptus best oil.............. 120
Everson process 5
Fatigue of solutions 60
Final disposal—Hoover app....... 118
Flow of—Hoover app. 117
Flowing away—ditto 114
Formed by bubbles.............. 56
Glogner's patent 28
Greenway, Sulman & Higgins 36
Hoover patent 36
Horwood's method 88, 89
Increases surface 58
Insoluble producers—list 120
Insolubles to promote 59
Maleczek's patent 21
Minerals Separation 10
Metallic scum—De Bavay 93
Mineral froth 60
Normal temperature production .. 75
Phenomena observable 60
Potter's dense froth 80
Potter test—formation 75
Prevents bubbles breaking 86
Produced with vacuum 78
Produced without oil 59
Quantity oil used 120

PAGE

Froth—
Rouse's patent 21
Simpler tester's disadvantage 73
Skimming with spoon............ 73
Slime present—Minerals Sep. 112
Soda-syphon froth 73
Soluble frothing agents 59
Soluble paradox 60
Soluble producer 120
Solubles used 60
Some addition necessary 59
Spoon for skimming 73
Substances useful 59
Test leakages 65
Tests—running off 68
Thickness of 58
Thickness in tests 68
What is froth ? 60, 79
Unused early De Bavay 92
Vannering De Bavay scum 93
Frothing Agents—
Advantages of 120
Fuel—
Cost—Potter-Delprat 91
Economics of 166
Fuel and Fluxes, see Working Costs.
Fuel Oil, see Oil.

Galena, see also Lead—
Difficult separation—Elmore...... 103
Gas adherence to—Potter 83, 84
Gangue, see also Separation—
Acid and water adhesiveness 53, 54, 56
Aversion to oil 53
Barite 103
,, easily separable 159
Broken Hill tailing 111
Causing to sink 2
Change of colour 60, 67
Composition—B. H. Propy. 81
Crushing free from 112
Disposal of—Elmore 99
,, Potter 85
Draining of—Potter 85
Feeble gas-oil adhesiveness 53
Felspathic—Edmundian mine 106
Felspar easily treated............ 159
Flotation of 43
Garnet, Broken Hill 81, 111, 103, 104
Gravity—Zinc Corp. 104
Heavy gangue separation 103
,, Traag mine 107
Hoover app. 117
Hornblende 107
Leaps baffle—Hoover app. 114
Not coagulated 60
Potter-outlet 82
Preference for water 56
Quartzitic—Garpensberg mine 107
Rhodonite................. 104, 111
Schistose—Dolgelly Mine 104
Schistose ores amenable 159
Separation by agitation — Everson 4
Separating graphite from 27
Settlement in tests 68
Silicious 2
Slaty Micaceous—Ramsley mine .. 104
Spathic iron 103
Stibnite 160
Sulitelma—Micaceous schist 108
Sulphide coagulation—effect 60
Telemarken mine................ 107
Tendency to float 125
Zinc Corporation 104
Garnet—
Broken Hill gangue 111
B. H. Propy. tailing 81
Difficult separation 103

PAGE

Garnet—
Zinc Corp. gangue 104
Garpensberg Mine, Sweden—
Description of ore 107
" plant 107
Number of units 107
Uses Elmore 107
Gas—
Ability to condense 57
Affinity-particles and gas 3
Air in fine subdivision 13
Attachment when generated 57
Bubbles of hydrogen 32
Bubbles used 29
Carbonic acid used 59
Carbon dioxide buoyancy 80
" excess 89
Chlorine gas—De Bavay 93
" obscure effect 95
Composition of 57
CO_2 75
Fine state of subdivision 9
Function of Chlorine 95
Gas dissolved in water 34
Gas producer—Elmore 102
Generation by electrolysis 30
Insufficient gasification 60
Introduction by agitation—Min. Sep. 10
Limitation and differential flotation 102
Maleczek's bubbles 21
Mickle—gas-bubble ....
Milky appearance 78
Mixtures of gases, liquids and solids 4
No mention by Potter 8, 24
Oil adhesiveness to 53
Potter—Carbon dioxide 82
Power to occlude 57
Quantity soluble 98
Selective action 25
" Potter 82
Spray gas introduction 10
Too rapid production 89
Gas Film, see Film.
Gas-Flotation, see Flotation.
Gas Generation—
Potter method 81
Gas Tar Derivatives 59
Gasification—
With chlorine—De Bavay 95
With mechanical agitation 78
General Expenses, see Working Cost.
General Expenses—
Cost—Potter-Delprat 91
Gillies, James H. 3
Based on Potter principles 14
Block 10 dump-purchase 90
Installed Block 10 14
Patents described 31
Production 90
Glasdir Mine, Wales—
Elmore developed process here 6
Robson & Crowder first tried 6
Glass Observation Windows 65
Glogner, Moritz F. R.—
Desc. of patent 28
Glue—
Deleterious to frothing 79
Gold—
Readily concentrated—Elmore ... 103
Sutton's patent 22
Sulman—Float gold 22
Gold-Bearing Pyrite 12
Good, Israel F.—
Patent described 30
Goyder 3, 17
Goyder & Laughton—
First machine introduced 86

PAGE

Goyder & Laughton—
Illustration of 28
Low capacity machine 86
Patent described 27, 28
Test-tube experiments 75
Trap machine 86
Grade of Ore, see Ore.
Granulation, see Sulphides.
Granulation Plant—
Minerals Sep. 123
Granules, see Sulphides.
Graphite—
Flotation 156
McCourt process 33
Separation from gangue 27, 30
Gravitation—
Feed 139
Gravity, see also Flotation 58, 59
Zinc Corp. gangue 104
Gravity-Concentration—
Broken Hill 111
Grease, see Oil.
Greased Needle, see Surface Tension.
Greenway, H. H. 3, 17, 111
Greenway, Sulman, & Higgins—
Patent described 36, 37
Gregory, S.—
Formation of Minerals Separation .. 9
Grinding, see also Crushing.
Grinding, see Working Costs.
Gummosity, see Concentrates, Organic Compounds—
Of concentrate—Potter 80
Gummy Organic Compounds—
Replacing oil—Potter 80
Gummy Sulphides 120

Hadeland Mine, Norway—
Description of ore 107
" plant 107
Elmore used 107
High-grade concentrate 107
Haultain 3
Haultain & Stovel—
Patent described 24
Similar apparatus—Wolf 30
Hay—
Elmore's action against 44
Haynes, William 3
Not flotation process 4, 18
Patent described 18
Sulphide-gangue separation 19
Head—
Hoover app. 117, 118
Head Room—
Saving—Hoover app. 115
Heat—
Acid introduction temperature ... 82
Boiling agitation mass 33
Boiler for tests 73
Cooling sulphides—Potter 84
Cooling the oil 26
Delprat uses 25
Everson—boiling water 5
Expulsion of oil 105
Haynes uses heat 18
Heating cost—Potter 90
Heating in tests 67
Hoover apparatus 113
Maleczek—hot oil 21
Potter uses 24
Steam feed—Hoover 116
Steam or air blown in 12
Suitable temperature—Potter 85
Super-heated steam—Potter 85
Temperature 57
Temperature regulation 135
Variation in temperature 71

PAGE

Heat—
Washing concentrate with hot water 12
Wolf process 12, 27
Hebbard, James—
Indebtedness to .... iii.
Hebron, Charles B. 5
Hebron & Everson—
Buoyant material rubbed in 21
Heat and vacuum used 21
Patent described 21
Radical departure 21
Henry & Dalton's Law 98
Utilized 34
Higgins, A. Howard 3, 17, 111
Indebtedness to .... iii.
Patent described 36
High Pressure, see Pressure.
Historical 1
Hockley, Edgar A.—
Patent described 21
Hoover Apparatus—
Acid feed 113, 116
Agitators 113
Agitation & mixing 121
Agitators (number of) 119
Agitators' peripheral speed 113
Air into pulp 113
Alternative arrangement 115
Apertures 113
Ascension of pulp 117
Baffle 113, 114, 117
Belt & gears 113
Capacity 114, 119
Centrifugal agitation 116
Changes—nature of ore 119
Concentrate produced 114
Dense froth 114
Description 113–123
Elimination—pipes, pumps, valves 121
Enormous air-introduction 113
Equal inflow & outflow 113
Extreme compactness 118
Feeding in pulp 113
Feeding oil, acid, water 121
Front to front 119
Further agitation & aeration 114, 117
Further improvement 121
Froth emergence 114
Gangue leaps baffle 114
Gangue passage 117
Head 117, 118
High-speed agitators 116
Horizontal lip 113
Horse power required 119
Illustrations 112–123
,, front elevation 116
,, longitudinal section .. 114
,, plan 117
,, side elevation 118
Improvements 113
Independent of operator 121
Inflow of pulp 113
In front of one man 119
Ingredients thoroughly mixed 113
Labour required 119
Latest form described 116
Less subsequent agitation 114
Limits of apertures 113
Lip 117, 118, 121
Live steam 113
Mixing compartments (new) .. 116, 117
Minerals Separation 113
Mixing & agitating compartments .. 113
Modified spitzkasten 113
Most recent form 115
Nest of boxes 114
Oil feed 113, 116
One liquid level 117

Hoover Apparatus—
One man 1,000 tons per day 119
Ore feed 116
Outflow—left to middle 113
Overall dimensions 119
Passage of pulp 116
Patent described 36, 37
Proportion oil & acid 113
Pulp agitated 116
Pulp churned violently 113
Pulp disposal 113
Pulp lines compartment 113
Pulp over baffle 113
Pulp pump—agitator 118
Rate of pulp flow 114
Re-arrangement for ore 119
Right compartment 114
Saving of space 115
Side elevation 118
Simpler mechanical arrangement .. 115
Spitzkasten & baffle 118
Spitzkasten (new) 116
Steam feed 116
Sulphide-bubble froth 114
Sulphide flotation 121
Temperature of pulp 113
Variations of connections 119
Various forms of 119
Water feed 116
Water level 113
Hoover Laboratory Sizer 132
Hoover & Sulman—
Anticipation of Norris 45
Patent described 35
Horizontal Section Decreasing in Area Upward—
Van der Naillen 23
Merrill 24
Goyder & Laughton 28
Hornblende—
Telemarken mine 107
Horses & Drays, see Working Costs.
Horwood, Edward James 3
Process described ...... 36, 147—149
Slime treatment idea 88
Sulphide separation 157
Hot Water, see Water.
Howard, A. C.—
Indebtedness to .... iii.
Hyde, James M. 3
Indebtedness to .... iii.
Hyde Process—
Butte & Superior Copper Co. use .. 17
Description of process ....
.... 16, 37, 149 to 153
First adopted U.S. 17
High-grade concentrate 38
Low grade 10 high 16
Uses acid 16
,, agitation 16
,, copperas 16
,, coagulation 16
Hylton, C. J.—
Indebtedness to .... iii.
Hysteresis 57
Effect of acid 57
Of silica 57
Range and contact angle 79
Illustrations—
A. Z. Agitator—De Bavay 93
Block 14 plant flow-sheet 87
Bradford apparatus 19
Broken Hill Proprietary plant 81
B. H. Proprietary plant 88
Central tailing dump 127
Contact angles 57
Elmore plant 99, 100
Flow-sheet 106

PAGE

Illustrations—
Flotation cones—De Bavay 94
Goyder & Laughton 28
Granule flotation 76
Hoover apparatus 112–123
Horwood 147
Hyde's testing machine 64
„ transverse section 66
„ plan 66
„ section 65
Macquisten tube 142, 144
Minerals Separation apparatus 112
Molecules (imaginary) 51
New Central plant flow-sheet 126
Potter 82
Potter-Delprat 84, 87
„ flow-sheet 83
Sanders process 146
Simpler testing machine 74
Surface tension diagrams 55, 56
Telemarken plant 108
Flow-sheet 109
Test diagrams..........69, 70, 71, 72
Tube with pocket 76
Wolf machine 27
Zinc tailing heaps 89

Infringement, see Patents.
Injunction, see Patents.
Insoluble Matter—
Difficulties with 134
High percentage 134
Iron. Broken Hill gangue 111
Iron Carbonate—
B. H. P. tailing 81
Iron pyrite—
Dolgelly mine 104
Garpensberg Mine, Sweden 107
Scandinavian ores 156
Sulitelma mine 108
„ residues 110
Iron Pyrite Carrying Gold—
Easily concentrated—Elmore 103
Iron Sulphate 16

James Brothers—
Reported on Robson & Crowder .. 6
Jet, see machinery.

Kendall, Cosmo 3
Patent described 27
Kerosene, see Oil.
Kirby, Edmund B.—
Patent described 30
Klein, John—
Patent described 23
Klug, George C.—
Indebtedness to .... iii.

Labour—
Cost—Potter-Delprat 91
Economics 166
Saving—Hoover app. 115
Labour of Others—
Indebtedness to .... iii.
Latimer, James Francis 3
Patent 34
Laughton 3
Lavers, Henry 3, 17, 111
Indebtedness to .... iii.
Law of Henry & Dalton 34, 98
Laws—
Underlying processes .... iii.
Le Roi—
Used old Elmore process 7
Lead, see also Galena—
Assay—Broken Hill tailing 112
Assay—De Bavay 97

PAGE

Lead, see also Galena—
Assays—Proprietary 91
Assay—Wilfley concentrate 105
Assay—Zinc Corporation 104
Saxberget 110
Tailing—Broken Hill 111
Traag mine, Norway 107
Zinc Corp. concentrate 104, 140
Lead Concentration—
Zinc Corp. tailing 104
Block 14 86
Lead Minerals—
Difficult separation—Elmore 103
Lead Recovery, see Recovery.
Leechman, John—
Indebtedness to .... iii.
Limestone, see Calcite.
Limitations of Flotation 154
Ancient & new magnetic method .. 1
Lip, see Overflow, Machinery.
Liquid—
Composition of 57
Level—Hoover app. 117
Litigation .... 39 to 48
Potter & Delprat 88
Lockwood, Alfred Arthur 3
Patents 37
Lockwood & Samuel—
Invented Murex process 15
Patent 35
Patent described 36
Locomotive Traction, see Working Costs.
Loss—
Copper in tailing—Sulitelma 108

Machinery & Apparatus—
A. Z. Agitator—De Bavay 92
Accurate surfaces 67
Agate-ware dishes 67
Agitator-arms 67
Agitator central tube 92
Agitators—Minerals Sep. 120
Agitator—normal speed 67
„ rack & pinion 92
Allis-Chalmers Anaconda mill 107
Air-jets—Potter 85
Air-lifts—Potter 85
Air-pump 75
Baffle 113, 114, 117
Ball-mill house—Sulitelma 109
Belt conveyors 127
Bicycle pump 73
Bins 81
„ concrete 130
Blind pocket—functions 82
Blind-pocketed vat 81
Bottom outflow—Potter 85
Bradford apparatus 19
Bucket elevator—slime 87
Bucket tramway 125
Buddle 34
„ tailing-bin 87
Burettes 67
Californian stamp-battery 104
Callow settlers 131, 138, 139
Cast-iron flotation boxes 88
Centrifugal apparatus 7
„ pump 89
Challenge feeders 130, 131
Chutes 131, 141
Collecting vat obstructions 82
Concrete tanks 139
Concentrating tables—Potter 83
Conical separator—Elmore 99
Conveyors 88
Crushing plant—Garpensberg mine 107
De Bavay cones—corrugations ... 95
Defective mechanical application .. 6

PAGE

Machinery & Apparatus—
Distributing tank—Potter 83
Draining tanks.............. 139, 141
Driving-shaft pulleys 120
Edgar Allen ball-mill 103
Electrical furnace—Saxberget 110
Elevators 131, 139, 140
Elmore's apparatus 13, 98
,, foundations unnecessary .. 101
,, greased belt 23
,, mixer 100
,, revolving drum..........6, 23
,, settling tanks........... 110
,, thickening tanks 109
Feed-pipe—Elmore 99
Ferraris wet ball-mills........ 107, 109
Filter bottom tanks 141
Flotation boxes—Potter 86
Flotation cones 93
,, vats 81
,, ,, capacity 85
Frue vanners 103
Gangue outlet—Potter 82
Gates crusher 107, 109
Gillies apparatus 14
Glass cylinder—Elmore 100
Glass jar 77
Goyder & Laughton machine .. 12, 86
Grinding-pans 81, 104
Grondal ball-mills—Saxberget 110
Haultain & Stovel's oiled belt 24
,, ,, machine 24
Haynes' triturating machine 18
Heater—Potter 83
Heberle ball-mills—Sulitelma 110
High-speed rolls 104
Holman pneumatic stamps 106
Hoover apparatus............ 10, 113
,, patent described 36
,, laboratory sizer 132
Horizontal section 23, 24, 28
Horse-tram—Sulitelma 109
Huntington mill 104
Hyde's testing machine 64
Hydrometer 136
Impeller mixer 132
Incline tram 87
Iron pipes 81
Iron trough 139
Jet floating sulphides 42
Jet recovering oil 42
Jigs—Sulitelma 108
Jigs & tables—Garpensberg 107
Krupp ball-mills—Hadeland 107
Launder—Potter 84
Loading gantry 130
Macquisten tube 14
Main driving shaft 120
Mason fruit jar 77
Metal cylinder—Elmore 100
Mixer—Elmore 99
Mixer box—Minerals Separation .. 132
Mixing-boxes—Minerals Sep. 120
Mixing device—De Bavay 92
Mixture of gases, liquids, solids .. 4
Montejus—De Bavay 93
Observation windows—Elmore ... 100
Oil-belt—Wynne 37
Oil-mixer 93
Oiling vat—De Bavay 93
Opening Mixers to Spitz 120
Overflow lip—Potter 83
Picking-belt 109
Pipettes 67
Pocketed vats 81
Pocket with outlet (vats) 81
Pocket without outlet (vats)...... 81
Pooley weigh-bridge............. 130

PAGE

Machinery & Apparatus—
Pressure gauge 75
Railway trucks 84
Rakes—Elmore 99
Reciprocating stone-breaker 104
Residues conveyor—Potter 83
Revolving screens—Zinc Corp. ... 104
Rolls—Garpensberg mine 107
,, Sulitelma 108
Rubber-belts........23, 24, 33, 37, 139
Rubber cushion 67
,, gangue belt 85
,, strakes 34
Rubbish trommel 130
Schwarz apparatus 29, 31, 33
Screens—revolving.......... 131, 137
Settling-pans—Scammell 25
,, tanks—Sulitelma 110
Simpler testing machine 73
Soda-water syphon 73
Solution sump—Potter 85
Solution vats—Potter............ 85
Spitzkasten 7
,, Min. Sep. 113, 114, 118, 120
,, Potter 83
Spoon for skimming............. 73
Spray introduced by Sulman & Picard 10, 29
Steam-shovel 88
Stone-breakers, Dolgelly.......... 104
,, Edmundian mine .. 106
,, Garpensberg 107
,, Saxberget 110
,, Sulitelma 108
,, Traag 107
Stone shipping bins 141
Stuffing-gland 67
Suction pump 77
Sump—Potter 83
Syphon—Elmore 99
Tables—Sulitelma 108
Tailing discharge—Elmore 99
Tank—Potter 83
Test agitator 65
Tests—windows 68
Test steam tube 67
Testing machine—description 65
Tin boiler for tests 67
Tram track—Zinc Corp. 130
V. Settler—Potter 83
Vacuum pumps—Sulitelma 108
Valve 67
Van Meter & Boss app. 8
Vanners—Sulitelma 108
Vanning plaque 76
Weir-Meredith vanners 138
Wet ball-mills—Garpensberg 107
Wilfleys 137
,, tables 105
,, ,, —slime 87
,, ,, —Traag 107
Wolf's greased belt 34
,, jet 42
Wooden tanks—Potter 84
Wormed wheel—Elmore 99
Macquisten, Arthur P. S. 3
Adelaide Reduction Wks., Nevada 14
Basic principle 77
Capacity 15
Desc. *in extenso*.......... 142 to 144
Federal Mining and Smelting Co. uses 15
Now uses oil................... 15
Patent described.......... 31, 33, 34
Test 77
Tube apparatus 14
Magnesium—
Broken Hill gangue 111

PAGE

Magnetic Concentration—
Sulphide Corp. production 86
Magnetic Flotation Method—
Lockwood process 37
Magnetic Ore Separation 1
Murex Oil increases magnetism . . . 15
Magnetic substances added 15, 36
Magnetic Qualities of Particles—
Disregard of 2
Magnetic Substances—
Addition of 15, 36
Magnetite—
Difficult Separation—Elmore 103
Garpensberg mine, Sweden 107
Hadeland mine, Norway 107
Sulitelma residues 110
Magnitude of Operations—
Economics 159
Maleczek—
Patent described 21
Mammoth Mining Co., Utah—
Used Butters' Elmore (Old) process 7
Material, see Tailing or Ore.
Mathematical Laws Underlying Process iii.
Maxwell, James Clark 49
Angle of contact 56
McCourt, Cyril Douglas—
Patent described 33
McCoy, John Henry—
Patent described 22
Mechanical Devices, see Machinery.
Mechanical Operations 1
Meniscus 53
Problem of 79
Merrill, Charles W.—
Patent described 24
Metal Content—
Estimation of—Potter 91
Metallic Scum, see Froth.
Metallic Sulphides, see Sulphides.
Metallurgical Processes, see Processes.
Metals, Recovery of 1
Methods of Separation—
Three enumerated 1, 2
Methyl Orange—
Testing acid solution 135
Micaceous Schist—
Telemarken mine 107
Sulitelma mine 108
Mickle, Kenneth A.—
Gas-bubble and oil 54
Microscopic Examination 56
Middling—
Block 14 & Potter 86
British dump purchased 89
Disposal of 137, 138
Mineral Particles, see Sulphides.
Minerals Separation—
Adopted by Zinc Corp. 129
Agitators—number required 120
Amalgamation with De Bavay . . 17, 92
Another form 122
Application 111
Can treat slimes 159
Conditions imposed 112
Considerable improvements 129
Cost of 128
Description of process 111
Description of work 128
Develops process 111
Dimensions of units 120
Directors, cordial thanks to . . . . . . iii.
Driving shaft pulleys 120
Elmore charges infringement 44
Essentially different 47
Formation of 9
Full description 111
Hoover apparatus 113

PAGE

Minerals Separation—
Illustration 112
Improvement—recent 119
Increase of surface 58
Justice Buckley's definition 42
„ Neville's „ 46
License to use 111
Lord Atkinson's definition 47
Main driving shaft 120
Minerals Sep. Ltd., owners 111
Mixing boxes required 120
New Central mill 125
Openings—Mixers to Spitz 120
Old granulation plant 123
Present process 10
Pulp treatment 113
Purchased Central tailings 11
Purchased Froment patent 9
Replaced Elmore—Zinc Corp. 106
Sectional sampling 133
Slime plant 124
Slimes—amount produced 112
Spitzkastens reqd. 120
Successfully tried Caucasus Cipper 11
Successful Central mine 127
Sulphide Corp. dump 128
Thickness of froth 58
Tried by Gillies 90
Used Great Fitzroy 11
Used Junction North mine, B. Hill 12
Used Lancefield, W. Australia 12
Used Orijarvi mine, Finland 11
Used San Francisco del Oro 12
Used Saxberget 110
Zinc Corp. material 131
Minerals Separation, Ltd., *v* De Bavay—Case described 48
Minerals Separation, Ltd., *v* Hyde—
Case described 48
Minerals Separation, Ltd., *v*. Norris—
Case described 45
Minerals Separation, Ltd., *v*. Potter—
Case described 45
Appeal described 45
Mispickel 12
Mitchell, Deane P.—
Indebtedness to . . . . iii.
Manager Zinc Corp. 16
Mixing Compartments, see Hoover Apparatus.
$MnCO_3$—
Broken Hill tailing 111
Moisture—
Excess in slime 138
Reduction in residue 139
Sampling for 130
Molecule, see also Theory—
Abnormally compensated 53
Free movement of 52
Imaginary illustration 51
Stress between 52
With uncompensated attractions . . 53
Molecular Activity or Aspects 50–54
Molybdenum Sulphides—
Difficult separation—Elmore 103
Molybdenite—
Flotation 156
Murex—
Description . . . . 15, 144—145
Installed Amalgamated Zinc 15
„ Block 14 15
„ Cordoba, Spain 15
Used in Bolivia and France 15

Namaqua Copper Co.—
Used Elmore 7
Native Metals—
Readily concentrated—Elmore . . . 103

PAGE

Natural Tendency, see Adhesion.
Neumann, S., & Co.—
Purchased interest in old Elmore process 7
New Central Mill 125
Nomenclature 50
Non-Acid Process—Sanders 35
Norris, Dudley Hiram 3
Air-introduction patent 45
Patent described 35
North Broken Hill Mining Co.—
First used De Bavay 92
Nutter, Edward H.—
Indebtedness to .... iii.

Occlusion, see Bubbles.
Oil—
Addition of—Zinc Corp. 132
Addition during tests 67
Addition of petrol 76
Avoidance of waste 135
Attacks rubber belts 139
Affinity for sulphides—Haynes 4
Blast-furnace—Elmore 101
Borneo—Elmore 101
Breaking up or emulsifying 7
Burned off for re-treatment .. 13, 105
Burning off insolubles 120
California crude—Elmore 101
Castor oil—De Bavay 93
Coagulation without 79
Composition of—De Bavay 93
Cooling the oil 26
Cylinder oil 77
De Bavay adopts 14, 92
De-oiling by heat 13, 105
Economics of 165
Elmore's large variety 101
Enhanced adhesion—Potter 85
Essential oils 59
Essential oil gasification 78
Everson process 20
Feed—Hoover 116, 121
Feeding device—Hoover 113
Fish oil—Elmore 101
Froment's discovery 9, 25
Fuel oil—Elmore 101
Gasification by kerosene 78
Hot oil—Maleczek 21
Increased selective action 36
Insoluble oil replaced 120
Introduced as spray—Sulman & Picard 10
Kerosene—De Bavay 93
„ Elmore 101
Large quantity used 22
Light oils—Elmore 101
Measuring for tests 63
Not used—Potter 85
Oil-amalgamation 23
Oiled pumice, oiled charcoal 25
„ tailing—De Bavay 93
Olive residues—Elmore 101
Oleic acid—Elmore 101
Proportion used—Cattermole .. 10, 25
„ De Bavay 93
„ Everson 5
„ Elmore .. 7, 13, 101
„ Hoover app. 113
„ Minerals Sep. .. 10
„ Maximum effect . 69
„ Sulman, Picard & Ballot 33
Recovery with alkali 26
Residual oil 77
Result of addition 55
Russian crude—Elmore 101
Selective action—Cattermole 25

PAGE

Oil—
Selective action increased 15, 23
„ Robson & Crowder .. 6, 22
„ Elmore 23
„ priority 46
„ Haultain 24
Solid grease 30
Sulpho-chlorinated oil—Wolf .. 12, 27
„ „ Scammel .. 25
Sumatra oil—Elmore 101
Sutton employs 22
Tar used as—Elmore 101
Tests—various 71
Texas crude—Elmore 101
Texas residuum—Elmore 101
Thick black oil—Everson 5
Tin recovery unaffected 103
Unused—Early De Bavay 92
Old Granulation Plant, see Minerals Separation.
Oleaginous Process, see Oil.
Oleic Acid, see Acid.
Ore—
Base metal 1
Change of colour 60
Concentration of 1
Cornwall tin ore 103
Crushing to fineness 1
Dolgelly mine—grade 104
Dry ore treatment 19, 32
Edmundian mine—assay 106
Feed—Hoover app. 116
Garpensberg mine, Sweden 107
„ assays 107
Hadeland mine, Norway 107
Haynes grinds fine 18
Heavily mineralized—Garpensberg 107
Hyde's Machine useful 73
Ideal ore 155
Oxidised ore process 37
Per cent. mineral 102
Possible organic components 80
Pulverised ore (Everson) 5
Ramsley—Grade of 104
Saxberget mine—desc. 110
Sulitelma mine 107
„ description of ore .. 108
„ low-grade 108
„ hand-sorted 108
„ milling 109
„ smelting 109
Telemarken mine, Norway 107
„ ore sorted 107
Traag mine, Norway 107
Unamenable to Potter 43
Untreatable 6
Untreatable—Delprat successful .. 8
Yields 16% conc. 102
Ore Concentration Company, Ltd., *v.* Webster et al—
Case summarized 43
New trial 44
Compromise 45
Organic Compounds, Gummy—
Possible ore components 80
Organic Matter—
Acid and gumminess 86
Present in tailings 86
Producing gumminess—Potter 80
Orr, Homer L.—
Patent described 29
Overflow—
Clarification 139
De Bavay cones 95
Elmore machine 99
Elmore vacuum process 98
Feet of lip 59
From vats—Potter 84

PAGE

Overflow—
Hoover apparatus 113, 117, 118, 121
Hyde overflows water 16
Of acid—Potter 82
Of froth—Potter 83
Robson & Crowder—oil 6, 22
Sulphide discharge—Elmore 100
Water 138
Over-size 137
Elmore—Zinc Corp. 104
Re-crushing—Elmore 104
Ox-gall—
Deleterious to frothing 79
Oxidation of minerals 26
Zinc Corp. material.............. 105
Oxide Minerals—
Limitations of flotation 154
Oxide of Tin—
Difficult separation—Elmore...... 103
Oxidized Ores, see Ore.

Particles, see Sulphide.
Patent Law considered 39
Patents—
Acid no infringement 47
Action against Webster 43
Breakdown of patent law 39
à Beckett invalidates Potter...... 43
Careful search 18
Cases summarized .... 41 to 48
Changed situation 39
Chronological order preserved 18
Clashing 39
Darling's decision quashed 44
Decided cases 40
Elmore's non-priority 47
Elmore non-suited 44
Hoover—Minerals Sep. 116
House of Lord's decision 47
Justice à Beckett's decision 45
,, Buckley's decision 41, 42
,, Darling's decision 44
L. Justice Farwell's decision 46
,, Fletcher Moulton's dec. 46
Justice Neville's decision 46
,, ,, reversed.. 47
Justice Parker 44
Litigation considered 48
Litigation inconclusive 48
Lord Ashbourne's decision 48
Lord Atkinson's decision 47
Lord Halsbury's decision 47
Lord Shaw's decision 48
Macquisten patent upheld 42
Minerals Sep.—no infringement by 46
Mostly English patents 18
Necessity of examination 40
Number summarised 39
Oil-film no infringement.......... 47
Oil selective action priority 46
Potter absorbs Delprat 43
Prior use of acid 46
Privy Council decision........... 45
Recent Potter patents 85
Secrecy of knowledge 40
Undecided cases 48
United States patents 18
Patents (expired) 18–22
Patents (unexpired) .... 22 to 38
Peaty Water, see Water.
Penalty for Moisture 138
Penetration of Surface—
Implied by wetting 55
Percentage Distribution—
Elmore 106
Percentage Metal Distribution ....
.... 131, 132, 133, 134, 135
Percentage of Extraction, see Extraction.

PAGE

Permission to Publish Data—
Courtesy Minerals Separation .... iii.
Petrol, see Oil.
Phenols 59
Froth producers 120
Physical Laws, see Theories.
Physical Laws Underlying Process .... iii.
Picard, Hugh F. K.. 3
Indebtedness to .... iii.
Minerals Separation formed 9
Plane Surface, see Surface.
Potter, Charles V. .... 3 & 80
Potter Process—
Abandoned 89
Acid-flotation process 81
Acid-salt-cake 81
Air-lifts 85
Amenable to re-treatment 86
Amount of acid 90
Application overcoming invalidity . 45
Application of process 86
Assaying ore useless 43
Basis of compromise—Delprat 80
Carbonic acid replacement 79
Carbon-dioxide gas 81
Coagulation of pulp 85
Cost of acid 90
Cost of plant 86
Described in extenso (Potter-Delprat) 80
Dense froth 83
Disposal of gangue 85
Easy construction 86
Final bubble loss 84
Flow-sheet 83
Flotation-box lining 86
,, trouble 86
Froth formation test 75
Gas-flotation (Potter-Delprat) 80
Generation of gas 81
Gillies plant 90
,, dismantled 90
Has reached finality 86
Heating cost.................... 90
Illustrations .. 81, 82, 83, 84, 87, 88, 89
Increase of surface 58
Installation British mine 89
Legal quandary 80
Litigation & compromise 80
No moving parts 85
No oil used now 85
Oil-enhanced adhesion........... 85
Overflow of acid 82
Patents described 24
Power charge 90
Power required 85
Production of concentrates 85
Principle disclosed by Goyder & L. 12
Priority of date 80
Proprietary results poor.......... 91
Quantity water used 90
Recent patents 85
Repairs cost small 85
Royalty 80
Simplicity of idea 86
Simultaneity of idea 80
Slime treatment devt. 159
Solution vat-level 85
Speed of operation 85
Spent tailings solution........... 85
Suitable temperature 85
Super-heated steam 85
Tailing fed mechanically 82
Test-calcite 75
Tests—Description 75
Thickness of froth 58
Treats once only 85
Washing concentrates............ 84

PAGE

Potter Process—
Working cost analysed 90
,, table 91
Zinc Corporation 89
Zinc Corporation unsuccessful 16
Zinc Corporation experiments 85
Zinc industry commencement 86
Potter Sulphide Company—
Owns world rights 80
Potter *v.* The Broken Hill Proprietary Co.—
Appeal and Compromise 43
Case summarised 42
Potter *v.* The Sulphide Corporation, Ltd.—
Case described 48
Power—
Cost—Potter-Delprat 91
Economics 165
Elmore pulp flow 99
Hoover app. 119
Potter 85, 90
Elmore 100
Requirements of 90
Preferential Oiling, see Oil.
Pressure 27
Applied to pulp 34
A flotation force 57
High-pressure dissolution 35
In soda syphon 75
Price, F. Glynn—Indebtedness to .... iii.
Privy Council, see Patents.
Problems Suggested for Research...... 79
Processes—
Detrimental effect of litigation 40
Devt. by Minerals Sep. 111
Outcome of many minds 2
Potter uses gas-flotation 80
Question of credit due to individuals 2
Some—air-flotation 80
Question of ownership 2
Product—
Concentrates—Potter 85
Macquisten product contents 15
Delprat to 1907 88
Gillies plant 90
Horwood process 89
Proprietary—Table 91
Tonnage 160
Products of Wood Distillation—
Frothing agents 120
Profits 162
Progress, Interim report of .... iii.
Proportion—
Water to ore 112
Proprietary Company—
Metal content 91
Pulp—
Aeration of—De Bavay 95
Ascension—Hoover app.......... 117
Cattermole 10
Draining and immersing 34
Elmore subjected vacuum 13
Equal inflow and outflow 113
Flotation of—De Bavay 13
Freely-flowing pulp—Elmore 6
Further agitation—Hoover....... 114
Hoover apparatus 113
Inflow—Hoover app. 113
No sizing—Elmore 101
Passing of—Hoover 116
Present Minerals Separation 10
Pressure applied to 34
Prop. water to ore 112
Ramsley mine—Elmore 104
Rate of flow—Minerals Sep....... 114
,, Elmore 99
Ratio air—Elmore 102
Ratio water—Elmore 102

PAGE

Pulp—
Sulitelma—Excess water......... 110
Telemarken mine................ 107
Temperature—Hoover app. 113
Treatment—Minerals Sep. 113
Treatment—Traag mine 107
Pyrite 62
Sulitelma mine.................. 108

Quantitative Results—
On small scale 64
Quartz—
Adhesiveness to water........... 53
B. H. Propy tailing 81
Feeble gas-oil adhesiveness....... 53
Telemarken mine................ 107
Zinc Corp. gangue 104
Quartzitic Gangue, see Gangue.

Ramsley Mine, Devonshire—
Elmore used 104
Ratio of Concentration, see Concentration.
Ratio of Feed—
Concentrate—De Bavay 97
Lead concentrate—De Bavay 97
Zinc Conc.—De Bavay 97
Ratio of Pulp, see Pulp.
Recovery—
At Proprietary plant 91
Bornite 157
De Bavay 96
Difference in tests 73
Edmundian mine................ 106
Enhanced by oil—De Bavay 14
High-grade..................... 38
High-grade concentrate 38
Lead concentrate—De Bavay 97
Lead recovery 87
Lead—Saxberget 110
Minerals Separation.......... 11, 141
New Central Mill 127
Potter-Delprat 91
Proprietary—Table 91
Telemarken mine................ 107
Tests—various oils 71
Total concentrate—De Bavay 97
Wolf process.................... 12
Zinc concentrate—De Bavay 97
Zinc Corp. Min. Sep. 141
Re-Crushing—
Garpensberg mine 107
Potter process 81
Re-flotation 134
Concentrate calibration 137
,, disposal of 137
Residue – table.................. 135
Re-grinding—
Delprat 87
Reluctance to Float—
Broken Hill tailing 112
,, sulphides 112
Research Problems 79
Residual Oil, see Oil.
Residue—
Assay residue—Elmore 105
Elmore tonnage 105
Disposal of—Potter 83
From re-flotation................ 135
Sloppy nature 139
Sulitelma 108
Rejection of 136
Resinous Substance—
Schwarz........................ 31
Re-treatment—
Failure—Block 10 slimes 124
No re-treatment 128
Of concentrates—Potter 86
,, Wilfley-Elmore 105.

PAGE

Re-treatment—
  Potter readily amenable 86
Re-treatment Plant—
  Amalgamated Zinc 96
Rhodonite—
  Broken Hill gangue 111
  B. H. Propy tailing 81
  Zinc Corp. gangue 104
Roast—
  Horwood 157
  Sulman & Picard 37
  Preliminary roast—Dick 36
  Wentworth process 36
Robson 3
Robson & Crowder—
  Process outlined 6
  Patent described 22
Rock, Waste, Worthless, see Gangue.
Rouse, Albion M.—
  Patent described 21
Royalty—
  Potter-Delprat 80
  Economics of 163
Ruthenburg, Marcus—
  Patent described 35
Salaries, see Working Cost.
Salt Cake—
  Delprat test 76
  Manufacture of 76
  Potter-Delprat 8, 25
  Potter's process 81
Salt Solution Excess—
  Unsound reasoning 119
Salts in Solution—
  Certain increase detrimental .. 119
  In water 119
  Obviating bad effect 119
Samuel 3
San Francisco Del Oro—
  Refractory 156
Sand—
  Potter success on sand 9
Sand-Residue 139
Sanders, Walter Murray 3
  Patent described 32
  Process described .... 145—146
Santa Barbara Mine, Peru—
  Used Van Meter & Boss 8
Saponin—
  Powerfully deleterious 78
Saxberget Mine, Sweden—
  Descr. of ore 110
  „ plant 110
  Treat. of ore 110
  Uses Minerals Separation 110
  Uses Elmore 110
Saygun Mine, Wales—
  Used Elmore (Old) Process 7
Scammel, Joseph Barton 3
Scammel Process—
  Justice Buckley's definition .. 41
  Patent described 25, 26
Schistose Gangue, see Gangue.
Schwarz, Alfred 3
  Patent described 29, 31, 33
  Theory advanced unacceptable .. 29
Schwarz, Alice H.—
  Patent described 30
Scum, see Froth or Film.
Selective Action of Gas, see Gas.
Selective Adhesion, see Oil.
Separable Compounds—
  Enumerated 103
Separation, see also Concentration—
  Ancient method 1
Separation—
  Magnetic methods—limitations .. 1
  Magnetic ore—separation 1

PAGE

Separation—
  Potter's high separation 43
  Potter's separation partial ... 43
  Sulphides from gangue 1
  „ economics 157
  Third method evolved 2
Series of Trials—
  Consistency of pulp 112
Silicious Gangue, see Gangue.
Silver—
  Assay B.H. tailing 112
  Assay—De Bavay 97
  Assays—Proprietary 91
  Assay—Wilfley product 105
  Assay—Zinc Corporation 104
  Dolgelly ore 104
  Readily concentrated—Elmore ... 103
  Saxberget 110
  Zinc Corp. Concentrate 104
Simultaneity of Idea—
  Potter and Delprat 80
Sintering—
  De-sliming for 87
S_2O_2—
  Br. Hill tailing 111
Sizing—
  Elmore—Zinc Corp. 105
Skimming—
  Delprat 25
  Froth with spoon 73
  Scammell 25
  Spoon for skimming 73
  Third or fourth operation 73
St. David's Mine, Wales—
  Used Elmore (old) process 7
Slime—
  Agitation, aeration, warming .. 61
  Bucket elevator for 8
  Block 10 and Central 11
  Cattermole adds sulphide 10
  Contains calcite 89
  De Bavay—careful de-sliming ... 95
  Delprat *v.* Potter 42
  De-sliming for sintering 87
  Difficulty of draining 138
  Discarded—De Bavay 92
  Disposal—Zinc Corp. 132, 138
  Economics 158
  Excessive sliming—Traag 107
  Flotation considered effective 11
  Horwood's idea 88
  Hyde coagulates 16
  Macquisten cannot handle 15
  Minerals Sep.—amount 112
  Min. Sep. Slime plant 124
  Min. Sep. & Delprat alone handle 159
  Potter fails on slime 9
  Quantity discarded—De Bavay ... 96
  Rejection of residue 136, 139
  Sulitelma—bulk slimed 110
  Slime-deposition 30
  Treatment 158
  Untreatable by Delprat 88
  „ without coagulation 60
  Wilfley tables for 87
  Zinc Corp. plant Min. Sep. 137, 138
  Zinc slime saleable 138
Specific Gravities—
  Disregard of 2
Spray, see Machinery.
Soap—
  Addition of 19, 60
  Action of—Cattermole 28
  Cattermole—proportion 10, 25
  Tunbridge uses 19
Sodium Sulphate, see Salt-cake.
Softness of Copper Mineral—
  Dolgelly Mine 104

PAGE

Solids—
Composition of 57
Proportion of water—Elmore 110
Surface of 57
Surface energy of 57
Soluble Frothing Agents, see Froth.
Soluble Salts—
Table for estimation 136
Solution—
Avoiding density 135, 136
Drawing off—De Bavay 93
Remedy 136
South Mine—
Quantity of tailing 96
Spathic Iron—
Hadeland Mine, Norway 107
Difficult separation—Elmore 103
Specific Gravity, see Gravity.
Speed—
Of flotation—Potter 85
Spherules—
Ratio of—Froment 25
Sprinkling—
Dry ore treatment 32
Starch—
Deleterious to frothing 79
Steam, see Heat.
Stevens, A. Sydney—
Indebtedness to .... iii.
Sticky, see Gummy.
Storm, R.—
On coagulation 60
Stovel 3
Strake, see Machinery.
Stratifying Apparatus 5
Subsequent Treatment of Concentrate .. 120
Sulitelma Mine, Norway 107
Assays—Concentrate 110
Capacity—Elmore 110
Clean lump pyrite 108
Description of ore 107
,, plant 108
Excellent technical supervision ... 108
Loss of copper 108
New Elmore machines ordered ... 110
No. of Elmore units 110
Tailing assays 110
Treatment of ore 108
Sulman, Henry Livingstone—
Boiling agitation mass 33
Contact angles 57
Exposing to air 35
'Float' gold recovery 22
Formation Minerals Sep. 9
High-pressure app. 35
Hysteresis 57
Indebtedness to .... iii. 3
Oxidized ore treatment 37
Patents described 33, 35, 111
Soap slime deposition 30
Uses agitation 33
Sulman & Picard—
Approaching book .... iii. 50
Introduced bubbles with spray 10
Patents described ....
.... 29, 30, 31, 32, 33, 37
Purchase by Webster 44
Sulman & Picard *v.* Wolf—
Case summarized 41
Sulman & Sulman—
Patent described 34
Sulman, Higgins, & Ballot—
Patent described 37
Sulman, Picard, & Ballot—
Patents described 31, 32, 33, 36, 111
Sulphide Corporation—
Alleged infringement by ....
First zinc production 86, 123

PAGE

Sulphide Corporation—
Lead mill tailing—Min. Sep. 10
Plant to treat current tailing 11
Sulphide Particles, see Sulphides.
Sulphides—
Adherence to oil 53
Affinity for oil 54
Assume films of air 34
Aversion to water 54
Blende—Hadeland Mine 107
Bradford process 19
Broken Hill blende assay 111
Carbon-dioxide adherence 80
Cattermole granulation 10, 25
Classifying when mixed 26
Coagulation of 60
Coagulating slimed sulphides 89
Collection of granules 28
Collection *v.* Flotation 42
Cone recovery—De Bavay 95
Cooling—Potter 84
Delprat *v.* Potter 42
Differential separation—Wentworth 37
Discharge—Elmore 100
Disposal of—Elmore 99
Enhanced adhesion—Potter 85
Everson process 4, 20
Film of carbonate—De Bavay 14
Film of—sulphides 92
Flotation of 2
Form of—Traag mine 107
Freed from gangue 1, 112
Friable resin blende—Traag 107
Froth—Hoover app. 114
Granule formation 29
Granulation 42
Gummy 120
Haynes's process 4
Hoover apparatus 121
In tin ore 103
Loose & sandy—Potter 86
Nitric acid solution 26
Non-floatable—Wentworth 36
Oil & gas methods 3
Oil-vanner separation 35
Potter's failures 43
Potter—gas adherence 82
Preferential oiling—Blount 54
Ratio air necessary 102
Separation of 1, 157
Separation from oil 77
Separating zinc from lead 36
Sinking *v.* flotation 42
Slime essential—Min. Sep. 112
Smelting to recover metals 1
Spitzkasten separation 14
Stronger magnetic permeability .. 1
Test flotation—granules 75
Trapping at surface 27
Wetted with difficulty 53
Zinc sulphide flotation 55
Zinc—Zinc Corp. 104
Sulpho-Chlorinated Oil, see Oil.
Sulphur—
Sulitelma ore 108
Sulphuric Acid, see Acid.
Sulphuric Acid Works—
Sulitelma pyrite 108
Super-Atmospheric Pressure 27, 56
Superficial Area—
Increase of bubbles 58
Superheated Steam, see Heat.
Superintendence—
Cost—Potter-Delprat 91
Supplies—
Economics of 165
Cost—Potter-Delprat 91

PAGE

Surface—
Liquid surface curved 57
Methods of increasing............ 58
Of particles—cleaning 93
Of water....................... 123
Penetration of 58
Plane surface.................... 57
Power of buoyancy 59
Shape of 57
Square ft. of.................... 59
Surface Activity 53, 54, 57
Surface Energy—
Of solids....................... 57
Surface Factor—
Increase of..................... 58
Surface Film—
De Bavay process 58
Surface Flotation, see Flotation.
Surface Units—
Increase of..................... 58
Surface Tension—
Accelerating factors............ 9, 92
Actual working capacity......... 59
Adequate without enhancement .. 59
Air-exposed surface.............. 51
Application to tube 42
Bradford process 4
First used 19
Breaking of bubbles............. 12
Cohesion considered 52
Cohesion into resultants.......... 52
Combined with oil & gas flotation 32
De Bavay 14
Determination of 58
Difficulty of measuring 50
Dislike of term 50
Dry ore treatment 32
Efficiency of utilisation 59
Elastic surface stretched 52
Enhancement of 59
Explanation of illustration 52
Floating oiled needle 50, 92
Force of water 50
Force resisting penetration 52
Free surface.................... 51
Functions of curve 57
Further experimentation changes.. 50
Greased needle 92
Illustration—imaginary molecules . 51
Ingalls explains definition 52
Ingalls' opinion................. 51
Interior and surface particles 51
Lb. produced per hour 59
Macquisten tube.............. 14, 31
Molecular attraction—resultants .. 52
Molecular energy 52
Nature of 50
Potter-Delprat 8, 80
Prevents penetration 55
Quantification of force 59
Resultants 52
Resultant forces uncompensated .. 52
Rupture of surface 50
Sulman diminishes 22
Surface layer pressure 52
Surface tension force 57
Tangent........................ 56
Text-book aid 50
Theoretical capacity 59
Theory of 50
Sutton, Joseph William 3
Patent described 21

Tables—
Analysis zinc conc. Min. Sep. 138
,, lead conc. 140
,, zinc.................. 140
Assay of tailings 112

PAGE

Tables—
Assay B. H. tailings 111
Annual production zinc conc...... 161
Average cost—all processes .. 164, 165
By-products at Broken Hill 160
Classification tests 138, 140
De Bavay recoveries 97
Dimensions of units—Min. Sep. .. 120
Effect fineness on recovery—Hyde 151
Elmore air consumption 102
Elmore—percentage distribution .. 106
Elmore tonnage 105
Elmore working costs 101
Estimating soluble salts 136
Guernica mine ore 155
Ideal ore—analysis 155
Min. Sep. old granulation plant .. 124
,, slime plant 125
,, "Central" plant 127
Recovery—Potter................ 91
Screen analysis—Hyde 152, 153
Series of tests 69
,, ... 70
Sulphide dump costs—Min. Sep. .. 128
Summary of flotation tests—Hyde 151
Temperature—grains per gallon .. 136
Utilisation—surface-tension 59
Working costs—Potter 91
Zinc Corp. costs—Min. Sep. 129
,, crushing feed 131
,, flotation concentrate .. 133
,, flotation plant 132
,, re-flotation conc. 134
,, re-flotation residue 135
,, Min. Sep. results 141
Tailing—
Assay—Dolgelly—Elmore 104
Assay—Zinc Corp........... 130, 131
Attempted treatment—Saxberget . 110
British dump purchased 89
Broken Hill material 111
,, assays 81
Clean Elmore tailings............ 103
Crushing brightens sulphides...... 112
Central mine—Min. Sep. 11
De Bavay washes from slime...... 14
Decrease of 161
Direct treatment—Elmore........ 104
Discharge—Elmore 99
Elmore—Sulitelma 110
Exhaustion 161
From spitzkasten................. 10
Feed—De Bavay................. 97
Feed tonnage 105
Fed mechanically—Potter........ 82
Final—Sulitelma 110
Illustration of heaps 89
Larger particles—reluctance 112
Must free from gangue........... 112
Necessity to crush 112
Oiling—De Bavay 93
Oversize—Zinc Corp. 104
Quantity—Block 10 96
,, North mine 96
,, South mine 96
Reasons for crushing 112
Re-grinding—Zinc Corp. 104
Removal of 88
Saxberget 110
Sulphide Corporation 10
Tin Oxide left 103
Tons produced—Proprietary...... 91
Tons treated—Proprietary........ 91
Wolf process.................... 12
Zinc Corp—fineness.............. 104
Zinc—Zinc Corp................. 104
Tailing Flume—
Hoover app..................... 118

PAGE

Tannin in Peaty Water 79
Tar—
Elmore—used as oil.............. 101
Technical Journals—
Indebtedness to .... iii.
Telemarken—
Desc. of ore 107
„ plant 107
Elmore used.................... 107
Flow-sheet 109
Illustration of plant.............. 108
No. of Elmore units.............. 107
Treatment of ore 107
Temperature, see Heat.
Tests 62, 79
Acid—maximum effect 70
Absence of carbonate 76
Addition of acid 67
Addition of oil.................. 67
Agitate energetically 63
Agitation—effect on oils.......... 72
„ period—effect.......... 71
„ speed—effect 71
„ time duplicated 65
Air dissolution 75
Approaching working conditions .. 72
Carbonate—Delprat 76
Colours of layers 63
De Bavay—described 76
Delprat process—desc. 76
Diagrams 69, 70, 71, 72
Disadvantage of skimming........ 73
Discharging soda syphon 75
Drops oil to gramme 63
Elmore, old and new 77
Enumeration of layers............ 68
Examination of product.......... 68
For the beginner 62
Gasification by agitation.......... 78
Glass windows 65
Goyder's tests 75
H2S gas fatal 70
Hyde's machine 64
Construction explained 68
Utility of 73
Ideal mixture 62
„ proportions 62
Increased acid effects 70
Leakage of froth 65
Lower window.................. 68
Macquisten process—described.... 77
Measure for shaking.............. 63
Measuring acid 63
„ oil 63
„ water 63
Methods of observation 69
No junction leakage.............. 67
Oil—maximum effect 69
Old Elmore—layers.............. 77
Oleic acid proportion 70
Other process tests 75
Persistence of froth.............. 63
Potter—calcite added............ 75
„ froth formation 75
Plaque tests—De Bavay 77
„ Macquisten 77
Potter process 75
Proportion of carbonate.......... 70
Proportionate recoveries.......... 73
Quantitative results impossible.... 64
Renewed agitation periods........ 73
Residue examination 68
Running test machine............ 67
Salt-cake test 76
Screening concentrates 69
„ tailings 69
Separation into layers............ 63
Series A—proportions 68

PAGE

Tests—
Series B—list 70
Second step 63
„ test—proportions 63
Series suggested 68
Simple agitator 65
Simpler testing machine.......... 73
Skimming froth 73
Speed of agitation 71
Soda syphon cap 73
„ froth 75
„ pressure 75
Soda water syphon 73
Speed of agitator................ 67
Standard test desirable 62
„ proportions 62
Steam boiler 73
„ introduction 67
Stuffing-gland 67
Temperature—effect 72
Time of agitation................ 71
Tube with pocket................ 76
Upper window 68
Variations in temperature 71
Variations suggested 70
Various oils 71
Violent agitation 72
Warm contents of tube 63
Waves—plaque test.............. 77
With second machine 73
Testing Machine—
Lip 68
Simpler form 73
Sliding off froth 68
Texas Fuel Oil (see Oil).
Theories of Concentration Processes involving Surface Tension—
Forthcoming work .... iii,
Transporting Agent (see Agent).
Theory (see also Molecules) ...... 49 to 61
Analogies instanced.............. 49
Cyanidation 49
Gas-film adhesion................ 50
Gold-ore amalgamation 49
Molecular considerations 49
Oleaginous adhesion 50
Quicksilver amalgamation 49
Theories, Consideration of 49
Thompson, George W.—
Indebtedness to .... iii.
Tin—
Cornwall tin ore 103
Oxide separation—Elmore........ 103
Tin Concentrate 103
Tin Oxides—
Left in tailing 103
Tonnage—
Elmore—Zinc Corp.............. 105
Production 161
Treated—De Bavay 97
Toughness of Rock—
Dolgelly mine 104
Traag Mine—
Assay 107
Desc. of plant 107
Elmore plant stopped............ 107
Excessive sliming................ 107
Heavy gangue 107
Number of units 107
Uses Elmore.................... 107
Tramming, see Working Costs.
Tube, see Macquisten.
Tunbridge, John 3
Patent described 19
Turpentine, see also Flotation Agent.
Froth producers 120
Tywarnhaile Mine, Cornwall—
Used Elmore (old) process........ 7

PAGE

Undecided Cases, see Patents.
Underground Filling, see Filling.
Underlying Forces, see Forces.

Vibration—
Absent—Elmore 101
Viscosity, see Oil (Sulpho-Chlorinated).
Vacuum, see Elmore—
Elmore process................13, 31
Hebron process.................. 21
Garpensberg mine 107
Vacuum Test—
Introduce no air 77
Van der Naillen, Edmund L.—
Patent described 23
Van Meter, James W................ 3
Van Meter and Boss Process 8
Patent described 29

Wages, see Working Costs.
Washing—
Clean water—Potter 84
Repeated—De Bavay............ 93
Waste Material—
Sulitelma 110
Waste Rock, see Gangue.
Sulitelma 109
Water, see Working Costs.
Water—
Air in solution 98
Brook water.................... 79
Cost—Potter-Delprat 90, 91
De-watering to pulp.............. 112
De-watering—Zinc Corp. 131
Distilled 78
Economics of 166
Excess water—Sulitelma 110
Feed—Hoover app. 116, 121
Highly aerated water 34
Hoover apparatus 113
Hyde overflows water............ 16
Latent acidity 119
Loss by evaporation 139
Measuring for tests 63
Overflow-clarification 138, 139
Peaty water deleterious 79
Proportion of—Elmore 102
Proportion to solid 110
Quantity used—Potter 90
Removal after crushing 81
Repeated employment 119
Robson & Crowder.............. 6
Salts in solution 119
Surplus—Telemarken............ 109
Upcast current—Cattermole .. 10, 28
White with agitation 113
Water Concentration, see also Concentration—
Inutility—Dolgelly mine 104
Inutility—Zinc. Corp............. 104
Sulitelma mine 108
,, residue assay 110
Tailing from—Sulitelma.......... 110
Unsatisfactory—Hadeland mine .. 107
Useless—Traag mine 107
Weathering—
De Bavay—Film of carbonate 14
Webster—
Elmore's action against 43, 44
Option on Elmore 44
Wentworth, Henry Azor.............. 3
Patent described 36
Wernher, Beit & Co.—
Interest in old Elmore process 8
Wilkinson, E. Ray—
Indebtedness to .... iii.
Wood, E. E.—
Indebtedness to .... iii.
Wold, Jacob D.—
Apparatus illustrated 27

PAGE

Wolf, Jacob D.—
Justice Buckley's definition 41
Patent described .. 27, 29, 30, 34, 37
Sulpho-chlorinated oil process 12, 27
Working Cost, see also Cost—
Br. Hill and U.S................. 159
Drying—Elmore 101
Elmore 101
Flotation—Minerals Sep. 128
Flotation—Elmore 101
Grinding—Elmore 101
Potter process analysed 90
Reports available................ 90
Re-treatment—Elmore 101
Sulphide dump—Min. Sep......... 128
Worthless Rock, see Gangue.
Wynne, Frank—
Patent 37

Young, Dr.—
Angle of contact 56

Zinc—
Assay B. H. Tailing.............. 112
Assay—De Bavay 97
Assays—Proprietary 91
Assay—Traag mine.............. 107
Assay—Wilfley product 105
Broken Hill gangue.............. 111
Broken Hill material 111
Difficult separations—Elmore 103
Recovery—lead by-products...... 2
Traag mine, Norway 107
Zinc Corp. concentrate 104
Zinc Blende—
Difficult separation—Elmore...... 103
Zinc Concentrate—
Zinc Corp....................... 140
Zinc Corporation—
Adopts Min. Sep................. 128
Amalgamation with S. Blocks 16
Assay—Concentrate 104
Assay—Material 104
Assay—Residue 105
Assay of tailing 130
Assays—Wilfley product.......... 105
Components of gangue 104
Crushing 105
Developed processes 15
Drying concentrates 104
Elmore abandoned 106
Elmore flow-sheet 106
Elmore tonnages 105
Flotation—Elmore 105
Full details treatment .... 129 to 141
Gravity of gangue 104
Installed Elmore 104
Minerals Sep. adopted............ 106
Most recent Hoover app. 115
Objects 15
Oxidation of mineral 105
Percentage distribution 106
Potter experiments.............. 85
Re-concentration product 105
Re-grinding tailings.............. 104
Removal of dumps 130
Re-treatment on Wilfley's........ 105
Sizing—Elmore 105
Tailing—Direct treatment........ 104
Tailing fineness.................. 104
Tried Potter process 9, 15, 89
Water concentration useless 104
Wilfley re-concentration.......... 105
Zinc-Lead-Silver Ore—
Saxberget mine 110
Zinc Plant, see Working Costs.
Zinc Slime, see Slime.
Zinc Sulphide, see Sulphide.
Zinc Tailing, see Tailing.
Zinc Treatment, see Working Costs.